HIERARCHAL GENETIC STRATIGRAPHY OF THE WREFORD LIMESTONE FORMATION (LOWER PERMIAN, GEARYAN) IN NORTHEASTERN KANSAS

by

TERRY R. BARRETT

B.S., University of Colorado, 1984

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

(Geology)

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

Approved by:

Major Professor

TABLE OF CONTENTS

LIST OF TABLES, AND FIGURES

ACKNOWLEDGEMENTS

Many thanks go to my adviser, Dr. Richard M. Busch, for his knowledge, support and guidance throughout this project, and for additional support and guidance outside the realm of this immediate project. I would also like to express deep appreciation to Dr. Ronald R. West, who served on my commitee and took over as my adviser at the tail end of the project, for his knowledge, encouragement and guidance throughout this project, and for his invaluable assistance in bringing this thesis to completion. And I thank the other members of my committee, Dr. Sambhuda Chaudhuri, and Dr. A. Paul Schwab for the help and insight they have given.

I thank my wife, Sharon, for her help and support, for doing some of the typing, and for surviving the completion of this project. Special thanks are given to my parents for their unending support and encouragement throughout my college career.

Gratitude is expressed to the Kansas Geological Survey, especially Dr. W. Lynn Watney, for providing support for my summer field expenses and for supplying topographic maps utilized in the field.

INTRODUCTION

The Lower Permian of the Midcontinent is well known for its laterally persistent, alternating layers of limestone and shale. These alternating layers of limestone and shale have traditionally been described and interpreted relative to idealized units composed of rhythmic or cyclic alternations of certain specific lithofacies. These lithostratigraphic units are termed cyclothems (after Wanless and Weller, 1932) by the North American Commission on Stratigraphic Nomenclature (1983).

Originally it was believed that these cyclothems were laterally persistant over a large portion of North America (e.g., Weller, 1930; Wanless and Weller, 1932). It has been noted, however, that only certain members (i.e., marker beds) of some cyclothems are laterally persistent across a basin (e.g., Busch, et al., 1985; Busch, 1987). This limits the accuracy of analyzing and correlating Permo-Carboniferous sections using the cyclothem approach. It has been shown (e.g., Busch, 1984) that it is more advantageous to describe and interpret these rocks relative to their constituent transgressive-regressive (i.e., deepening-shallowing) units, or "T-R units", by considering the total range of facies and facies-contacts present in a stratigraphic sequence.

For example, Busch, et al. (1985), Busch (1988), Bogina (1988), and Clark (1988) have shown that it is possible to

delineate a hierarchy of genetic transgressive-regressive units, or T-R units (after Busch and Rollins, 1984) within the Lower Permian of Kansas. They were able to do this only by considering all facies present in a stratigraphic interval, rather than considering only facies that are members of idealized cyclothems. These evaluations of the Lower Permian of Kansas were based upon an initial Punctuated Aggradational Cycle (PAC) approach to outcrop and core analysis. The PAC approach (Goodwin and Anderson, 1985) relies upon definition of small scale (1-5 meters) transgressive-regressive units (sixth-order T-R units of Busch and West, 1987). PACs constitute the smallest T-R units in the hierarchy of T-R units defined for Permo-Carboniferous sequences by Busch and Rollins (1984) and Busch and West (1987).

This study is an application of the hierarchal genetic (T-R unit) stratigraphic approach (Busch and West, 1987) as applied to the Wreford Limestone Formation (Lower Chase Group, Gearyan) of northeastern Kansas. As this study incorporates the PAC-approach for outcrop and core analysis, it is also an application of the Hypothesis of Punctuated Aggradational Cycles.

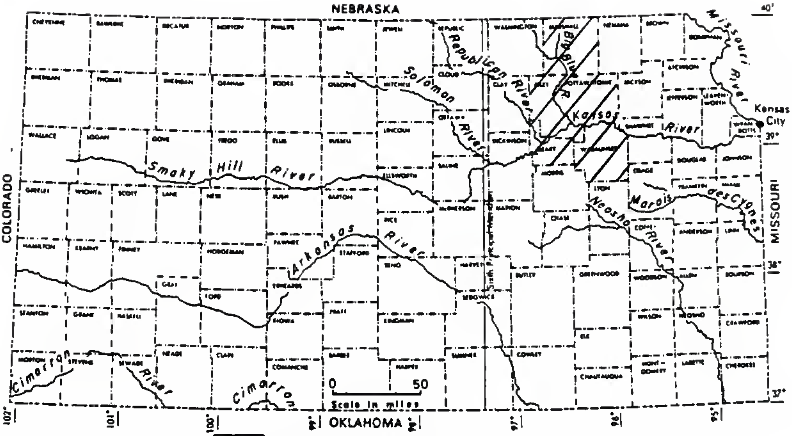
Area of Investigation

The Wreford Formation was investigated within a five county area of northeastern Kansas. These counties are Marshall, Riley, Geary, Pottawatomie, and Wabaunsee (Figure 1).

The western portion of the study area is bounded by the Great Plans Physiographic Province; the eastern portion lies within the Central Lowland Physiographic Province (Figure 2). The study area also encompasses portions of the Flint Hills Upland, named for its numerous, east-facing, cherty limestone escarpments.

Purpose and Objectives

The primary objective of this study is to evaluate the usefulness of describing and correlating Early Permian strata of the Wreford Limestone Formation (Lower Chase Group, Gearyan) in northeast Kansas using hierarchal genetic (T-R unit) stratigraphy (i.e., Busch and West, 1987) rather than the traditional, single-scale, cyclothem approach. Utilization of this hierarchal genetic stratigraphy will make it possible to interpret sea-level changes on a much finer scale than has previously been done.



- study area

Figure 1. Map of Kansas ahowing area of investigation (adapted from Zeller, 1968).

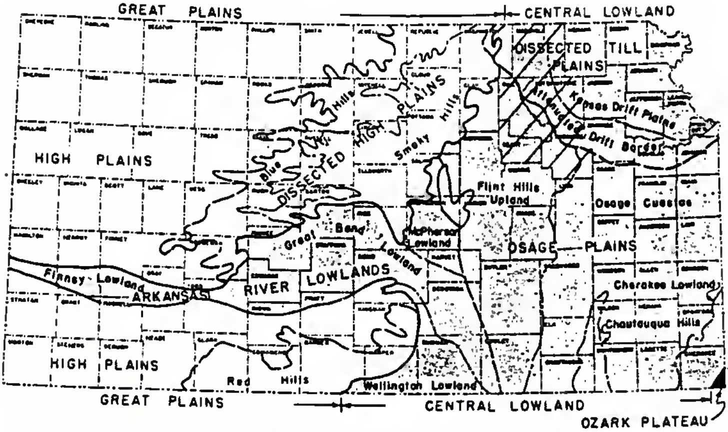


Figure 2. Physiographic map of Kansas (adapted from Schoewe, 1949, p. 276).

Another objective of this investigation is to use this detailed stratigraphic information to determine the detailed paleogeographic development of the Wreford Limestone. Paleogeographic and isopach maps can be drawn for times of maximum transgression and regression achieved in each sixth-order T-R unit. Using these maps, the development of the "Threemile fifth-order T-R unit" as a sequence of sixth-order T-R units (PACs) can be demonstrated and topographic highs and lows within the basin of deposition delineated. The maps will also define lateral changes in the biofacies and lithofacies at times of maximum trangression and regression within each sixth-order T-R unit.

Effects of local structural features on sedimentation during Wreford time can be examined. The detail achieved by using the hierarchal genetic-stratigraphic approach provides definition of cryptic structural features that controled sedimentation within the study area as shown by Busch (1984) in the Appalachian Basin.

Detailed field and laboratory data, obtained in this investigation, sheds light on the origin of the conspicuous layers of chert found in the Threemile Limestone member of the Wreford Limestone Formation.

Geologic Setting

Formal Lithostratigraphy.--The Lower Permian rocks in Kansas have been subdivided into two atages (Zeller, 1968): the Gearyan (below) and Cimarronian (above). The Gearyan Stage (O'Conner, 1963) was named for Geary County in northeastern Kansas and is composed of three groups, from oldest to youngest, the: Admire, Council Grove, and Chase.

The uppermost group of rocks in the Gearyan Stage is the Chase Group (Figure 3). It has a thickness of approximately 335 ft. (102 m) and consists of cherty limestones interbedded with variegated shales (Zeller, 1968). The Chase Group is composed of seven formations (Figure 3), including the basal Wreford Limestone Formation of this investigation. The Wreford Limestone was named by Hay (1893, p. 104) for exposures near Wreford, Geary County, Kansas that are no longer accessible. It contains three members, which are, in ascending order, the: Threemile limestone, Havensville shale, and Schroyer limestone.

The Threemile limestone was named by Moore (1936, p. 12) from an exposure near Threemile Creek in Riley County, Kansas. Originally Condra and Upp (1931, p. 31) had used the name Fourmile Limestone, but Moore (1936) change it to the Threemile limestone because the former name was preoccupied. No exact type locality was given by Moore; however, Hattin (1957, p.29) suggested that a suitable type locality could be

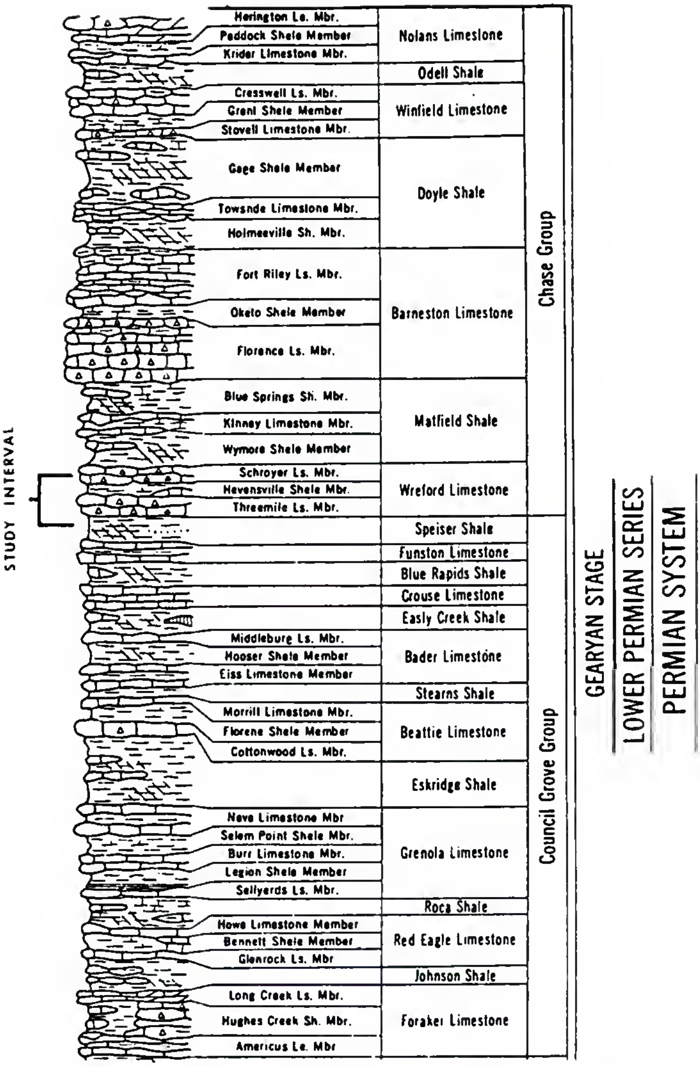


Figure 3. Stratigraphic column of part of the Kansas Permian, showing study interval (adapted from Zeller, 1968).

found in the NW1/4, SW1/4, sec. 11, T. 11 S., R. 6 E., on the Fort Riley Military Reservation, close to Threemile Creek. In general, the Threemile limestone consists of a basal, thick-bedded, cherty calcarenite with an average thickness in northeastern Kansas of 2 ft., 1 in.. This is overlain by a thin (average thickness 9 in.), laterally persistent, calcareous shale. The top of the member generally consists of thick-bedded calcilutite to calcarenite with an average thickness in northeastern Kansas of 7 ft. 4 in.. This upper portion is usually chalky (powdery on a fresh broken surface) and contains conspicuous layers of nodular and bedded chert. In Chase, Morris, and Wabaunsee Counties there is a dramatic thickening of this chalky limestone, commonly exceeding 20 ft. (Hattin, 1957, p.68). The occasional presence of <u>Stereostylus</u> and <u>Dibunophyllum</u> led Hattin (1957, p.69) to regard this abnormal thickening of the upper Threemile Limestone as "reef-like" in origin. Cuffey (1967, p.12) and Fry and Cuffey (1976, p.8) interpreted this chalky limestone facies, particularly in its thicker developments, as shallow-marine carbonate mud banks in which bryozoan colonies baffled suspended sediment and facilitated sediment buildup.

The Havensville shale was named by Condra and Upp (1931, p.32) from exposures on Kansas Highway 63, 2 miles south of Havensville, Pottawatomie County, Kansas. The Havensville shale generally consists of dark gray, olive green, and greenish-gray shales interbedded with thin beds of limestone.

It has an average thickness of approximately 22 ft.; however, in areas where the upper Threemile limestone is abnormally thick, it can be as thin as 1 ft. 6 in. (Hattin, 1957, p.69). At some isolated localities (e.g., Locality RY11 in Appendix, p. 228), there is a thick biostromal buildup of fossil debris forming a thick (10 ft. 5 in.), massive, skeletal limestone within the Havensville.

The Schroyer limestone was named by Condra and Upp (1931, p.33) for exposures 1 1/4 miles south of Schroyer, Marshall County, Kansas. In addition to the main cherty limestone, Condra and Upp (1931) included a subjacent, thin, noncherty, limestone bed (separated from the main cherty limestone by shale) as part of the Schroyer limestone. Alternatively, Hattin (1957, p.44) placed the base of the Schroyer limestone at the bottom of the first chert-bearing limestone above the Threemile limestone. His basic description of the Schroyer limestone includes a basal chert-bearing limestone, overlain by a thin calcareous shale or very argillaceous limestone, followed by a thick bedded, cherty limestone thought to be mainly algal in origin. According to Hattin (1957, p.49), the Schroyer limestone shows the least amount of lateral lithologic variation of Wreford Limestone members throughout Kansas. Very few complete surface exposures of the Schroyer limestone can be found because of the non-resistant nature of its upper portion. For this reason, the present study included only

those rocks found in the lower portion of the Schroyer limestone. Lack of complete exposures also makes estimating an average thickness difficult; however, Hattin (1957) gives a general thickness of 13 ft. for the member.

The upper portion of the Speiser Shale Formation (uppermost formation of the Council Grove Group) is genetically related to the Threemile limestone, and so it is also included in this study. The Speiser Shale was named by Condra and Upp (1931, p.23) for outcrops in Speiser Township, Richardson County, Nebraska. It consists mainly of red, greenish-gray, and yellowish-gray silty claystones and shales. A thin, laterally persistant limestone is usually present near the top of the Speiser, separated from the superjacent Threemile limestone by a calcareous shale. Hattin (1957, p. 55) informally referred to this limestone as the molluscan limestone, because the main diagnostic megafossils include Aviculopecten and, commonly, Septimyalina.

Chronostratigraphy.--In the past, numerous terms have been used to designate the lowermost series of Permian rocks in Kansas; these include the Big Blue Series, Wolfcampian Stage, and the Gearyan Stage (Figure 4). Named for exposures along the Big Blue River in northeastern Kansas, the term Big Blue was formally proposed by Prosser (1895). The Big Blue was formally recognized in 1896 by the Kansas and Nebraska Geological Surveys, as the lowermost series of rocks making up the Permian System in the northern Midcontinent

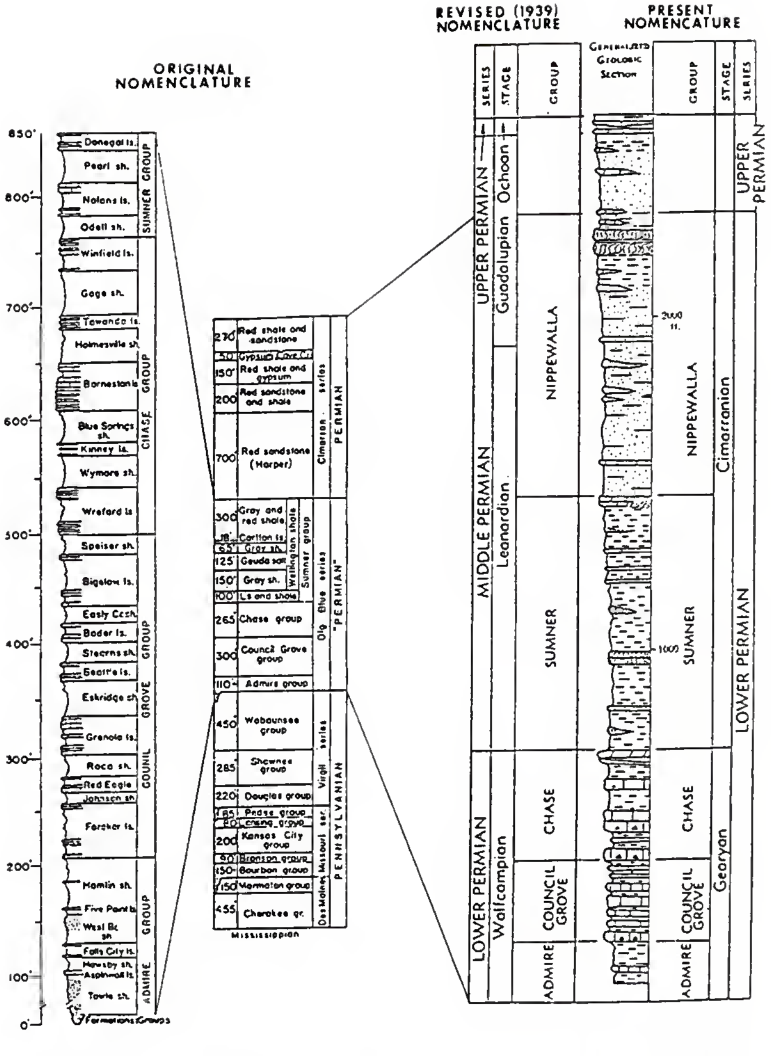


Figure 4. Stratigraphic aection showing formations and groups of the Big Blue Seriea to the left with revised (Adams, et al., 1939) and present nomenclature of Lower Permian strata to the right (modified from Elias, 1937, and Jewett, 1959).

(Cragin, 1896). The Big Blue Series consisted of four groups (Figure 4) which are, from bottom to top, the Admire, Council Grove, Chase, and Sumner. According to Elias (1937, p.404) the Big Blue Series correlated with the Wolfcamp beds of Texas, the Dunkard group of the Appalachian region, the Autrunian of France, the Lower Rotliegende of Germany, and the Upper Uralian of Russia. A correlation chart by Dunbar (1940) showed how the Big Blue Series related to other time stratigraphic units in the U.S.S.R., United States, and South China (Figure 5).

In 1939, in accordance with the established standard classification of the Permian section of North America (Adams et al., 1939, pp.1675-1681), the Kansas Geological Survey adopted the term Wolfcamp as the name of the lowest series in the Permian System. In the process, the uppermost group of rocks in the Big Blue Series, the Sumner Group, was designated as Leonardian, and the Admire, Council Grove, and Chase Groups were designated as Wolfcampian (Figure 4). Later, however, these West Texas Permian stage names (i.e., Wolfcampian, Leonardian, Guadalupian, and Ochoan), which had been adapted and used in Kansas nomenclature, were replaced by locally derived stage names (O'Conner 1963, p. 1875). The depositional environments and lithologies are different for the Glass Mountains Permian (Texas) and the Kansas Permian (O'Conner, 1963). For example, O'Conner (1963, p.1875) stated

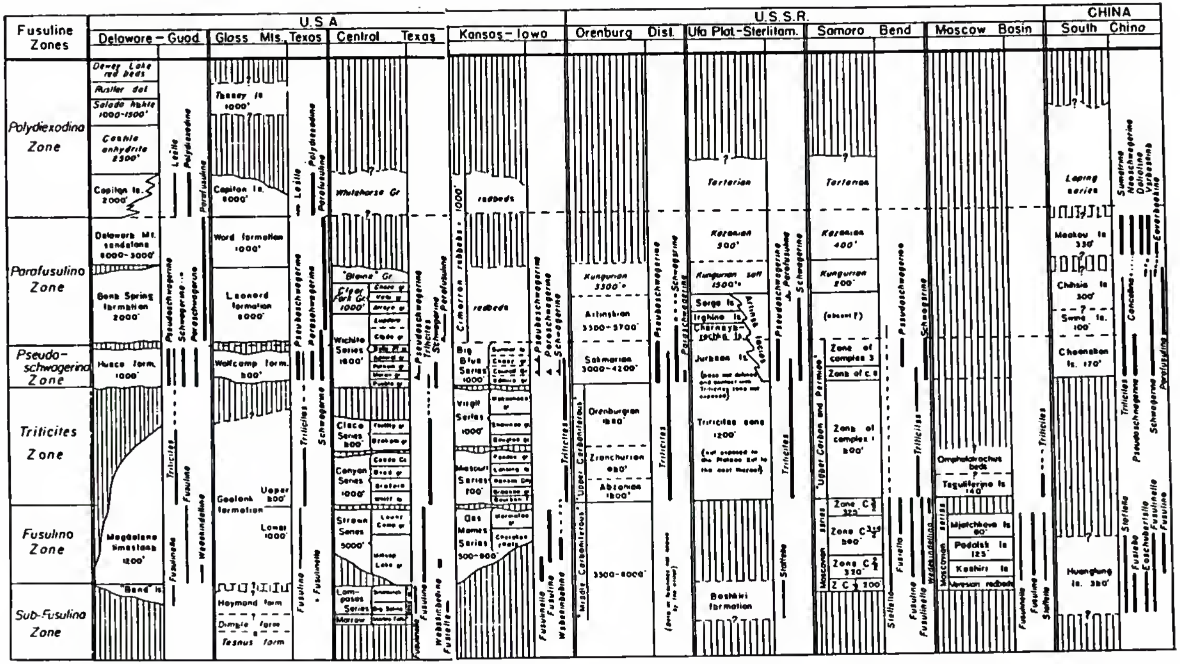


Figure 5. Correlation chart of Middle and Upper Carboniferous and Permian Formations in U.S.S.R., U.S.A., and South China, including the Big Blue series of Kansas-Iowa (from Dunbar, 1940).

that, "...it is not possible to relate the reef-rock section present in West Texas to the Kansas section with any degree of confidence." and that locally derived names would be more applicable for the Permian of Kansas and adjacent parts of Nebraska and Oklahoma. Therefore, the West Texas stage name Wolfcampian was replaced with Gearyan.

For purposes of this investigation, the Gearyan Stage is considered correlative with the Wolfcampian Stage. The Chase Group (Figure 6) is considered Upper Wolfcampian, with the Council Grove and Admire Groups making up the Lower Wolfcampian (Roscoe and Adler, 1983). The Gearyan Stage (Figure 7) is correlative with the Asselian and Sakmarian of Russia (Moscow basin, Southern and Ural region) and the Autunian of northwestern Europe, based on biostratigraphy (foraminiferids, ammonoids, conodonts, and/or bryozoans) and transgressive-regressive depositional sequences (Ross and Ross, 1985). Correlation of the Wolfcampian with other areas of the world can be seen in Figure 8. The estimated duration of the Gearyan Stage is approximately 18 to 20 m.y. (Ross and Ross, 1985; Harland, _et al_., 1982).

Geographic Extent.--The surface outcrop for the Wreford Limestone in Kansas is a nearly North-South belt from Northern Marshall County to Southern Cowley County (Figure 9). The Wreford outcrop extends northward into Nebraska for a distance of about 30 miles, then dissappears beneath the Cretaceous (Dakota) overlap (Newton, 1971, p.

SYSTEM		SERIES	STAGE	GROUP	FORMATION
PERMIAN		GUADALUPIAN			
PERMIAN		LEONARDIAN			Red Cave Ss
PERMIAN		WOLFCAMPIAN	UPPER	Chase, Pontotoc	Brown Dol
PERMIAN		WOLFCAMPIAN	LOWER	Council Grove, Admire, Pontotoc	
CARBONIFEROUS	PENNSYLVANIAN	UPPER	VIRGILIAN	Wabaunsee, Shawnee, Douglas	Laverty-Hoover Ss, Endicott Ss
CARBONIFEROUS	PENNSYLVANIAN	UPPER	MISSOURIAN	Lansing - Kansas City	Tonkawa Ss, Medrano Ss.
CARBONIFEROUS	PENNSYLVANIAN	MIDDLE	DESMOINESIAN	Marmaton	Oswego-Fort Scott Ls.
CARBONIFEROUS	PENNSYLVANIAN	MIDDLE	DESMOINESIAN	Cabaniss, Krebs, Cherokee, Deese	Bartlesville Ss.
CARBONIFEROUS	PENNSYLVANIAN	MIDDLE	ATOKAN		Thirteen-finger Ls.
CARBONIFEROUS	PENNSYLVANIAN	LOWER	MORROWAN		Wapanucka Ls, Wapanucka Sh, Union Valley-Cromwell Ss, Upper Morrow Ss., Keyes Ss.
CARBONIFEROUS	MISSISSIPPIAN	CHESTERIAN			Springer-Penn. Caney Fm
CARBONIFEROUS	MISSISSIPPIAN	MERAMECIAN			Mississippi Chat, Mississippi Ls.
CARBONIFEROUS	MISSISSIPPIAN	OSAGIAN			
CARBONIFEROUS	MISSISSIPPIAN	KINDERHOOKIAN			

Figure 6. Location of Chase Group within the Wolfcampian series (from Roscoe and Adler, 1983).

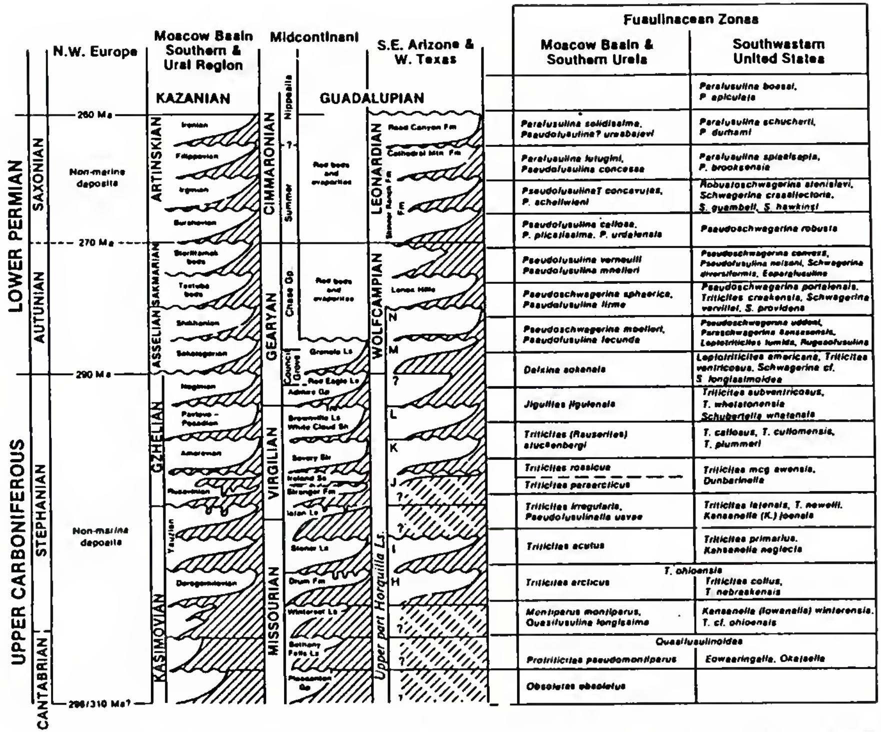


Figure 7. Correlation of Upper Carboniferous and Lower Permian strata based on biostratigraphy and transgressive-regressive sequences (from Roas and Ross, 1985).

Permian Period							PERMIAN SYSTEM					
Period	Epoch	Age	Chron	Biostratigraphic correlation: Fusulinid zones	Biostratigraphic correlation: Brachiopods	Ma	N.W. EUROPE (GERMANY)	U.S.S.R. EASTERN RUSSIAN PLATFORM	U.S.S.R. TIMAN	JAPAN	AUSTRALIA (QUEENSLAND)	U.S.A. (DELAWARE BASIN) LOWER PERMIAN
Permian (P)	Early (P_1)	Kungurian (Kun)	Irenian	*Neoschwagerina simplex*	*Pseudosyrinx*			IREN'SKIY	IREN' SKIY	NABEYAMAN	GEBBIE	LEONARDIAN
			Filippovian			263	WEISSLIEGENDES	FILIPPOVSKIY	VYL' SKIY			
		Artinskian (Art)	Baigendzinian	*Parafusulina kaerimizensis*	*Sowerbina*		ROTLIEGENDES	IKSKIY	KOMICHANSKIY			
					Antiquatonia							
			Aktastinian		*Jakutoproductus*	268			NERMINSKIY		SIRIUS SHALE	
		Sakmarian (Sak)	Sterlitamakian	*Pseudofusulina vulgaris*	*Tornquistia*			STERLITAMAK-SKIY	PEL' SKIY	SAKAMOTOZAWAN	TIVERTON	WOLFCAMPIAN
					Attenuatella						LIZZIE CREEK	
			Tastubian		*Yakovlevia*			TASTUBSKIY	ILIBEYSKIY			
		Asselian (Ass)	Krumaian	*Pseudoschwagerina morikawai*	*Tomiopsis*			KOKHANSKIY	NENETSKIY		BURNETT	
			Uskalikian		*Ortholichia*							
			Surenan		*Kochiproductus*	286		SOKOLYEGORSKIY	INDIGSKIY		JOE JOE	
C	Gze	Noginskian		*Triticites*						HIKAWAN		

Figure 8 . Correlation of Lower Permian strata in N.W. Europe, U.S.S.R., Japan, Australia, and United States (modified from Harland et al., 1982).

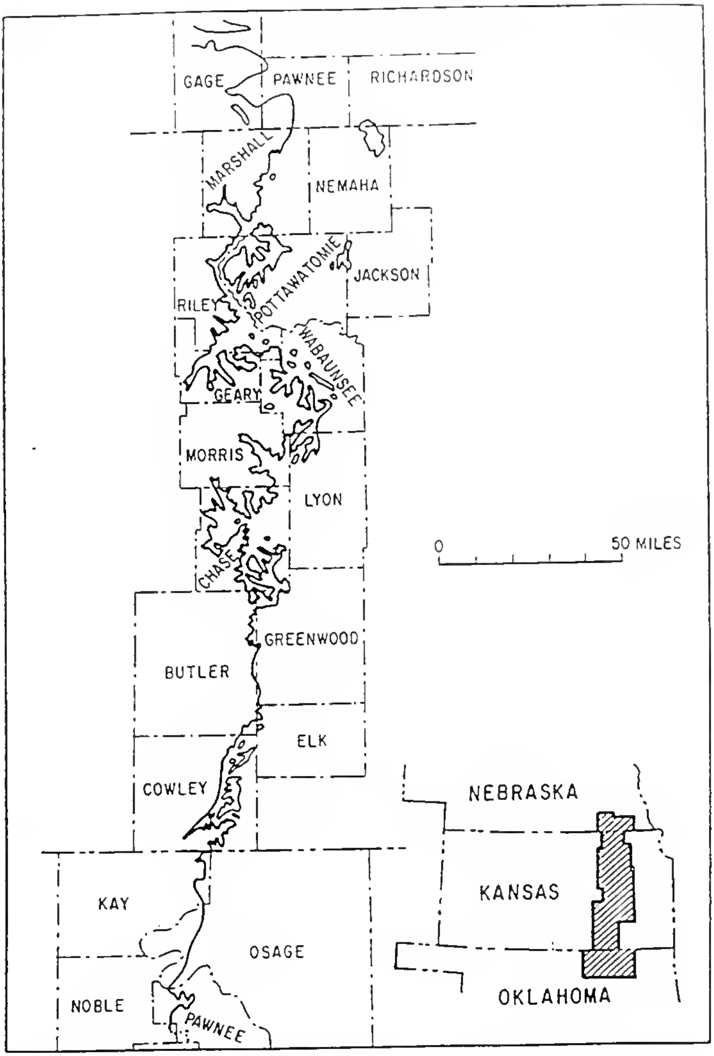


Figure 9. Outcrop of Wreford Limestone (Lower Permian) in Nebraska, Kansas, and Oklahoma (taken from Newton, 1971, p.11).

13). In Nebraska, the red shales of the Speiaer (continental deposits) increase in thickness, and are interbedded with, fine-grained fluvial sands (Newton 1971, p.13). This would suggest that at least one source-area for the silicilastic sediments found in the Speiser Shale and Wreford Limestone was located in the region of northern Nebraska, South Dakota, and western Iowa region (Newton, 1971).

Southward, the Wreford outcrop extends approximately 45 miles into northern Oklahoma. From north to south along this outcrop belt the red Speiser Shale also thickens, and becomes interbedded with, fluvial channel-sands (Grieg, 1959). Many of the thin limestone beds found in the Speiser and Havensville pinch out as the interbedded red shales and red channel-sands are encountered (Newton, 1971, p.14). This trend indicates that a southern aource area (Arbuckle and Ouachita uplifts, Figure 10) also supplied siliciclastic sediments to the Speiser Shale and Wreford Limestone. South of where the Wreford disappears in Oklahoma, the redbeds found above and below the Wreford merge and are collectively labelled the Stillwater Formation (Greig, 1959; Dott, 1941; Branson, 1960). A more detailed summary of the lithologic and nomenclature changes for the Wreford Limestone in Oklahoma is given by Newton (1971, p.13-14).

During Lower Permian time the Kansas region was located much closer to the equator than it is today. The estimated paleolatitude of the study area during deposition of the

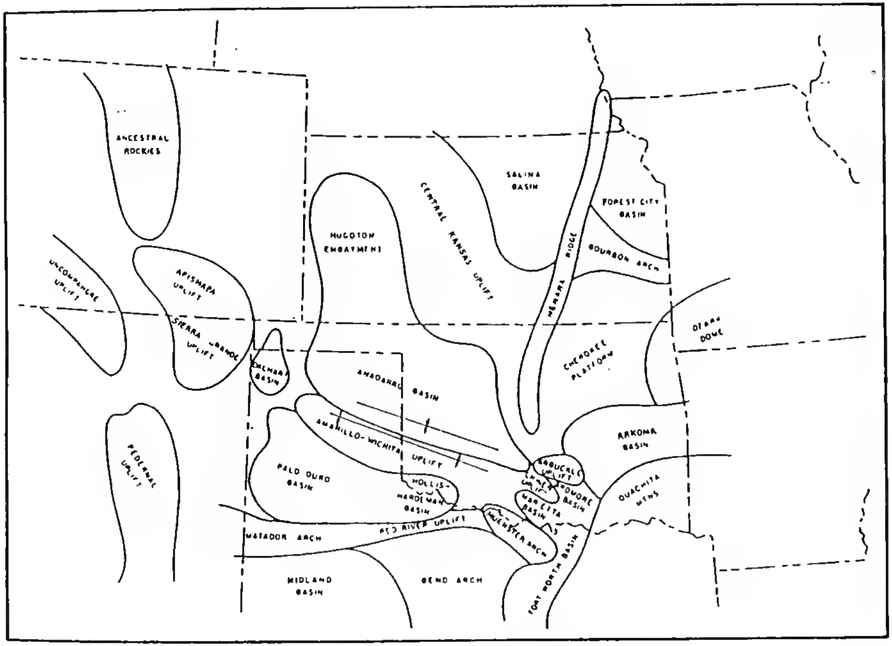


Figure 10. Major structural features in the midwestern United States showing possible southern siliciclastic source areas (Arbuckle uplift and Ouachita Mountains) for sediments in the Speiser Shale and Wreford Limestone (from Moore, 1979).

Wreford Formation was about 8 degrees south (Habicht, 1979, foldout 6).

Structural Setting.--Structurally, the study area lies mainly over the Nemaha anticline (Figure 11). The Irving syncline separates the Abilene anticline, in the northwest, from the Nemaha anticline. The study area is bordered on the west by the Salina Basin with the Sedgwick and Cherokee Basins to the southwest and southeast respectively. The Forest City Basin is east of the study area.

At the end of Mississippian deposition there was a phase of deformation during which the Nemaha Anticline, Abilene Anticline, and the Central Kansas Uplift were folded upward (Shenkel, 1959). Erosion took place over these structural highs removing much of the sedimentary rocks of Paleozoic age and in places exposing the Precambrian rocks. In Desmoinesian time (Pennsylvanian), seas again periodically invaded the northern Kansas area and deposition of marine and nonmarine sediments continued. It was this post-Misaissippian deformation that established the present structural pattern seen in Figure 11 (Shenkel, 1959). Intermittent minor deformation persisted throughout the Pennsylvanian and Permian as indicated by minor unconformities within these rocks (Shenkel, 1959). Minor deformation may even be continuing to the preaent time (Lee, 1954).

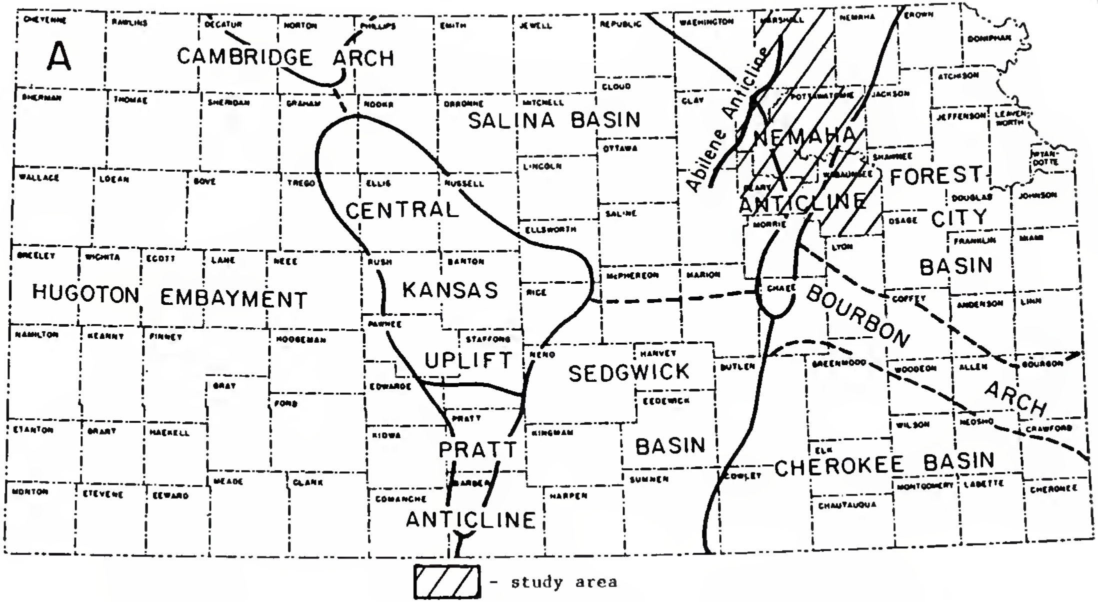


Figure 11. Map showing major structursl features of Kansas (from Shenkel, 1959).

All rocks in the study area are structurally included in the Prairie Plains monocline (i.e., the rocka dipping slightly to the west-northwest from the Ozark Plateau: Jewett, 1941, p.99) and dip about 15-20 feet per mile to the west-northwest.

Another noticeable structure-related feature in northeastern Kansas is the pronounced linearity of major atream and river valleys. Two orientations are prominent: north-northeast and northwest. These orientations follow major faults, fault zones, and/or joint patterns (Figure 12). For example, the Black Wolf fault follows the trace of the Smoky Hill River and the Cottonwood and Fall River faults parallel their namesake rivers (Berendson and Blair, 1986). Within the study area, the Big Blue River and Tuttle Creek Reservoir can also be seen to parallel local joint and fault patterns (Figure 12).

Previous Work.--The earliest description of Permian strata in Kansas that included the Wreford Limestone interval was published by Meek and Hayden (1860). The Wreford Limestone is represented by description number 18 (Meek and Hayden, 1860, p.17). Another early description of the Wreford Limestone interval was presented by Swallow (1866, p.11-16). The Wreford Limestone comprises beds 58 to 62 of his measured section near Fort Riley, Geary county, Kansas.

Hay (1893, p.104) formally named the Wreford Limestone from exposures in a quarry near Wreford, Geary County,

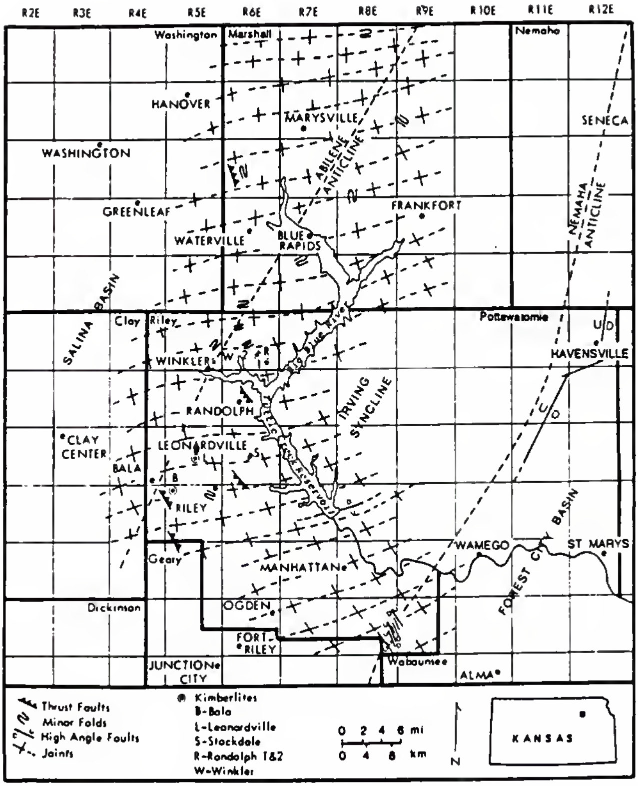


Figure 12. Map showing joint patterns and faults in the Manhattan Kansas area (taken from Underwood and Polson, 1988; originally adapted from Chelikowsky, 1972, p. 6). The north-northeast and northwest orientation of the Big Blue River and Tuttle Creek Reservoir are clearly seen.

Kansas, but Prosser (1895) proposed the name Strong Flint for the same rocks in Kansas, southern Nebraska, and northern Oklahoma. The name Wreford was kept, however, because it has priority and was not unsuitable for any reason. Hays' (1893, p.104) "Fort Riley Section" is shown in Figure 13. The Wreford Limestone is represented by description number 5 though Hay called it the Walford which I suspect was a printing error. Condra and Upp (1931) formally named all of the members of the Wreford Limestone and redefined the subjacent Speiser Shale.

The cyclicity of sedimentary units within the Permian System of Kansas was first noted by Jewett (1933). Jewett (1933, p.138) recognized a repetitive cycle containing four distinct lithologies (discussed below) in the Lower Permian of Kansas (Figure 14). Elias (1937) later published a model for an ideal "Big Blue" cycle of deposition for the Lower Permian rocks of Kansas (Figures 15-17). In that paper, he also discussed the paleoenvironmental significance (Figure 16) of the basic fossil assemblages found within the Big Blue Series (Gearyan Stage).

One of the most comprehensive studies dealing with the stratigraphic and environmental significance of facies within the Wreford Limestone was published by Hattin (1957). Hattin discussed, and gave paleoenvironmental interpretations for, different lithologies found in the Wreford Limestone, Spieser Shale, and Wymore Shale (Figures 18-19). He also formally

FORT RILEY SECTION.

PERMO-CARBONIFEROUS.

	Strata.	*Fossils.*	*Thickness.*
14.	Impure limestones, with some flints and numerous geodes.	A univalve......................	10 feet.
13.	Light-colored shales, with lavender flag beds.....	Athyris, pecten, pleurophorus..	60 to 60 ft.
12.	Buff limestones with shale partings, changing to shales with limestone ledges.	Pecten, nautilus, athyris, meekella, hemipronites, martinia, fenestella, euomphalus, synocladia, schizodus.	30 to 40 ft.
11.	The Fort Riley main ledge. A buff magnesian limestone in one thick ledge, with a thinner ledge resting on it. In places the ledges are continuous up into the layers of 12.	Pecten, allorisma, martinia, athyris, retzia, hemipronites, synocladia, fenestella........	6 feet.
10.	Shales, light colored and laminated	Producti, allorisma, chonetes...	15 "
9.	The upper flint beds. Limestones containing numerous flint nodules, and separated by definite layers of flints.	Producti, chonetes, allorisma, martinia	25 to 30 ft.
8.	Shales, alternate colors, grey, greenish, maroon, brown.	No fossils	30 feet.
7.	Limestone. The mid-shale bed, varying from a laminated, flaggy layer to a solid building stone.	Planorbis, and another univalve, allorisma, meekella, myalina, hemipronites, producti, etc...	6 "
6.	Shales, alternate colors, as No. 8..................	No fossils	16 "
5.	The lower flint beds. The Walford limestone. Flints as in No. 9. Parts of the beds are silicified in localities as if by infiltration.	Crinoids, syntrilasma, athyris, retzia, pinna, meekella, producti, cup corals..........	25 "
4.	Shales. Bands of maroon and greenish gray, with a seam of coal on Humboldt creek.	No fossils.......................	16 "
3.	Limestone in cuboidal or rhomboidal blocks. In places oölitic. A seam of coal under it on Humboldt.	....	4 "
2.	Shales, and buffy slate...........................	....	10 "
1.	Slate, bluish and hard..............................	Occasional discinae.............	10 "
Those outcrop beyond the east border of the district.	Shales, blue and lavender, with gypsum.	....	30 "
	White limestone...............	Many fossils	5 "

This is the horizon of the Marshall county saccharoidal gypsum.

Figure 13. Hays' (1893, p. 104) "Fort Riley Section" including a description of the Wreford Limestone (number 5).

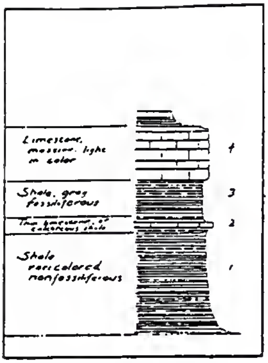
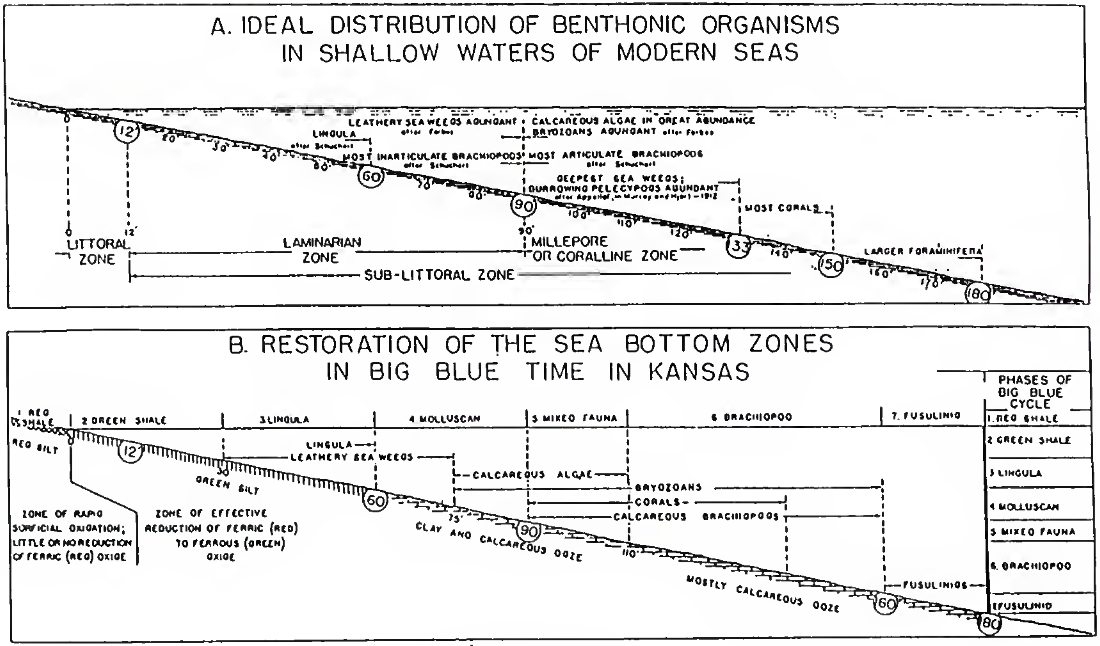


Figure 14. Jewetts' (1933) unita of a characteriatic cycle of sedimentation in the Lower Permian rocks of Kanaas (from Jewett, 1933, p. 138).

	No.	Phases established chiefly on paleontologic evidence	Corresponding typical lithology
Regressive hemicycle	1.	Red shale..................	Clayey to fine sandy shale, rarely consolidated.
	2r.	Green shale................	
	3r.	Lingula phase..............	Sandy, often varved (?), rarely clayey shale.
	4r.	Molluscan phase...........	Clayey shale, mudstone to bedded limestone.
	5r.	Mixed phase..............	Massive mudstone, shaly limestone.
	6r.	Brachiopod phase..........	Limestone, flint, calcareous shale.
	7.	Fusulinid phase............	
Progressive hemicycle	6p.	Brachiopod phase..........	
	5p.	Mixed phase...............	Massive mudstone, shaly limestone.
	4p.	Molluscan phase..........	Clayey shale, mudstone to bedded limestone.
	3p.	Lingula phase	Sandy, often varved (?), rarely clayey shale.
	2p	Green shale................	Clayey to fine sandy shale, rarely consolidated.
	1.	Red shale..................	

Figure 15. Elias' ideal Permian cyclothem (from Elias, 1937, p. 411).



By Maxim K Elias, 1935-1936

Figure 16. Sea-bottom zones in modern and in Big Blue seas (from Elias, 1937, p. 410).

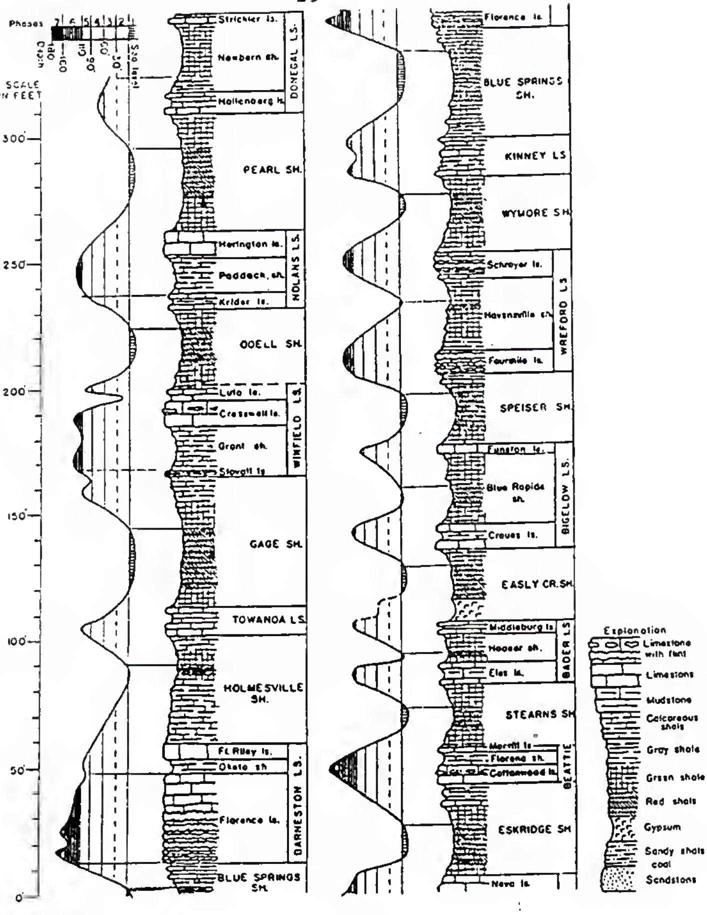


Figure 17. Composite geologic section of part of the Big Blue series in northern Kansas, interpreted in terms of cyclic sedimentation and depth of deposition (modified from Elias, 1937, p. 406).

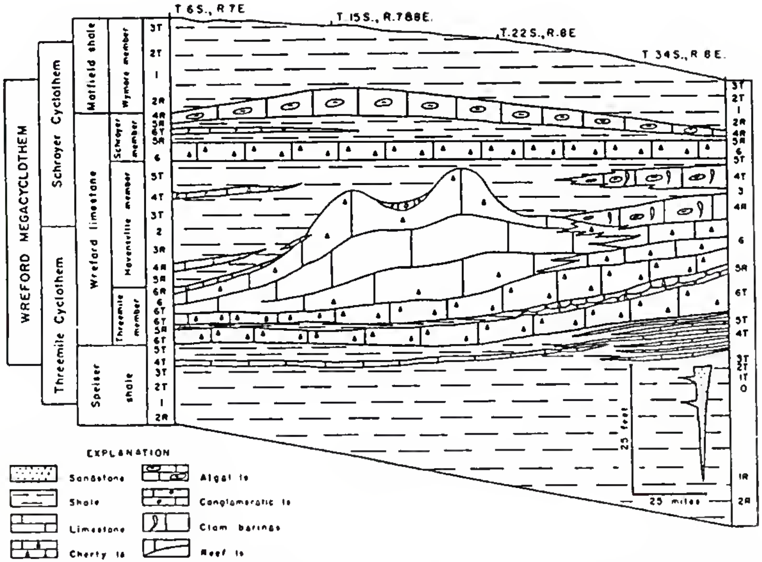


Figure 18. Relation of sedimentary depoaits in the Wreford megacyclothem (from Hattin, 1957, p. 105). Numbers refer to phases of depoaition (figure 19). Unlettered numbers are terminal phases of hemicycles (Hattin, 1957).

Cyclothem	Fm.	Mbr.	Phase	Description
SCHROYER CYCLOTHEM	MATFIELD SHALE	Wymore shale	1 .	Red shale
			2r.	Green shale, ostracodes
	WREFORD LIMESTONE	Schroyer limestone	4r.	Algal limestone
			5r.	Calcareous shale, mixed fauna, *Derbyia* dominant
			6 .	Chert-bearing limestone, brachiopod-bryozoan fauna
		Havensville shale	5t.	Calcareous shale, mixed fauna, *Derbyia* dominant
			4t.	Molluscan limestone, *Aviculopecten*, *Septimyalina*
			3t.	Grayish-yellow mudstone, ostracodes
THREEMILE CYCLOTHEM			2 .	Green shale, ostracodes and sparse plant remains
			3r.	Grayish-yellow mudstone, ostracodes
			4r.	Molluscan limestone, *Aviculopecten*, *Septimyolina*
			5r.	Calcareous shale, mixed fauna, *Derbyia* dominant
		Threemile limestone	6r.	Chert-bearing limestone, brachiopod-bryozoan fauna
			6 .	Chalky limestone, *Fenestrellina*, corals
			6t.	Chert-bearing limestone, brachiopod-bryozoan fauna
	SPEISER SHALE		5t.	Calcareous shale, mixed fauna, *Derbyia* dominant
			4t.	Molluscan limestone, *Aviculopecten*, *Septimyolina*
			3t.	Grayish-yellow mudstone, ostracodes
			2t.	Green shale, ostracodes and sparse plant remains
			1t.	Red shale, charophytes
			0 .	Sandstone, unfossiliferous

Numbering corresponds to that of Elias (1937, p. 411) where applicable. t=transgressive phase, r=regressive phase. End members of hemicycles are not lettered. (Minor regressions and transgressions not shown).

Figure 19. Observed sedimentary phases of the Wreford megacyclothem (from Hattin, 1957, p. 106).

proposed the name Wreford Megacyclothem (as discussed below) to define those rocks extending from the middle Speiser Shale up to the middle Wymore Shale (Figure 18). Other papers which deal with characteristics and paleoenvironmental aspects of the units within the Wreford Limestone have been published by Cuffey (1967, p. 10-13), and Newton (1971, p. 7-10). Lutz-Garihan and Cuffey (1979) addressed the stratigraphy and environmental significance of the Wreford Limestone facies in southernmost Kansas and northern Oklahoma. These authors recognized the same basic facies as those listed for the Wreford Megacyclothem by Hattin (1957, p. 104-106: figure 19). Using these facies, Cuffey (1967) and Lutz-Garihan and Cuffey (1979) split the Wreford Megacyclothem into 22 units.

Important information on the general description and outcrop location of the Wreford Limestone have been provided by Walters (1954) for Marshall County, Jewett (1941) for Riley and Geary Counties, and Mudge and Burton (1959) for Wabaunsee County.

Paleontological and paleoecological studies of the Wreford Limestone Formation have been common. Much work has been done on the paleoautecology of different bryozoans including tabuliporids (Cuffey, 1967), rhomboporoids (Newton, 1971), fistuliporoids (Warner and Cuffey, 1973; Fry and Cuffey, 1975, 1976), and the fenestrates, pinnates, and ctenostomes (Simonsen and Cuffey, 1980). Wreford

brachiopods, Composita in particular, have been studied by Lutz-Garihan (1976). Arthropods, including ostracodes, barnacles, and trilobites, found in the shales of the Wreford Limestone, were studied by Bifano, Guber, and Cuffey (1974), Simonsen and Cuffey (1980), Lutz-Garihan and Cuffey (1979), and Cuffey (1977). Fusulinids, in the lower Threemile Limestone of Chase County, were studied by Sanderson and Verville (1970).

In addition to studies of the different invertebrates of the Wreford Limestone, work on vertebrate fossils obtained from the Wreford Limestone and subjacent Spieser Shale has also been carried out (Hotton, 1959; Coldiron, 1978; Schultz, 1985).

Twenhofel (1919) discussed the origin of the chert in the Foraker and Wreford Limestones. He postulated a penecontemporaneous origin for the chert, but later (1950, p. 414) cast doubt on this theory. Subsequent work of the origin of chert in the Wreford Limestone Formation has been done by West, Barrett, and Twiss (1987).

Studies on the clay minerology of the Havensville Shale (including the origin of clay minerals, and their vertical and lateral distributions) have been done by Lee (1972) and Lee and Chaudhuri (1976). Isotopic data for the clay minerals in the Havensville Shale were discussed by Chaudhuri and Lee (1972). These studies suggest that the clay minerals

(especially illite) inherited radiogenic atrontium at the time of deposition, that the illites are detrital, and that clays from northern and southern Kansas were derived from different sources.

Chaudhuri (1976) discussed the significance of Rubidium-strontium ages of sedimentary rocks. He obtained Rb-Sr dates for samples from the Havensville Shale which ranged from 325 m.y. to 395 m.y. These measured dates are regarded as being intermediate between the ages of the source rock and the time of deposition and are not thought to be indicative of any geologic event (Chaudhuri, 1976, p.169).

Rare-earth element (REE) distributions in the clays of the Havensville Shale were studied by Cullers (1974) and Cullers and Chaudhuri (1975). They found that REE concentrations for samples collected from northern Oklahoma were higher than the REE concentrations for samples collected in Kansas. Possible explanations for this difference in REE concentrations include differing REE content in the source areas, exchange reactions in the environment of deposition, diagenesis, and chemical weathering in the source area; with the latter probably being the most significant (Cullers and Chaudhuri, 1975, p.588).

Cyclic Stratigraphy in the Wreford.--Traditionally the Wreford Limestone, as with most Permo-Carboniferous sequences, has been described and interpreted relative to

idealized cyclic or rhythmic vertical repetitions of lithofacies (cyclothems). Jewett (1933) was one of the first authors to describe the cyclicity of lithologic types found in the "Big Blue Series" (Gearyan) of Kansas. In a stratigraphic sequence extending from the Elmdale Formation (base of Hughes Creek Shale) to the Herrington Limestone, Jewett (1933) recognized ten repetitions, or cyclothems, each of which consisted of four lithofacies. These lithofacies, from bottom to top, include: (1) variegated shale, without fossils; (2) thin limestone or calcareous shale; (3) very fossiliferous gray or yellow shale; and (4) thick, massive, light-colored limestone (Figure 14). Jewett (1933) stated that the upper part of the Garrison Formation (Speiser Shale) and the overlying Wreford Limestone, as it is exposed in eastern Riley County Kansas, may be used as the type example of the cycle. He made no attempt, however, to relate paleoecology to his cycle of lithologic types.

Elias and Moore (1934) recognized a distinct cyclical succession within the rocks of the "Big Blue Series". Elias (1934) presented a symmetrical succession of lithofacies and fossil assemblages which form a succession of progressive and regressive hemicycles in the "Big Blue series".

A detailed study of the cyclicity and depth of deposition (Figure 16) of the rocks in the "Big Blue Series" (Gearyan) of Kansas, was carried out by Eliaa (1937). He defined an ideal Permian cyclothem that is symmetrical in

character, containing a progressive (trangressive) and regressive hemicycle (Figure 15). The progressive hemicycle consists of six phases: red shale, green shale, Lingula phase, molluscan phase, mixed phase, and brachiopod phase. A fusulinid phase separates the progressive hemicycle from the regressive hemicycle, which contains the same six phases as the former except in opposite order. Elias (1937) showed that the Wreford Limestone (including the subjacent and superjacent shales) comprises two complete cycles of sedimentation and parts of two more (Figure 17). Elias (1937, p.411) stated that "...no single cycle of the Big Blue rocks shows all phases of the ideal cycle, but missed phases in one cycle appear in proper position in neighboring cycles above and below."

Hattin (1957) defined the Wreford Limestone (including the subjacent Speiser, and superjacent Wymore shales) in terms of nine different lithofacies. He found that the Wreford Limestone showed a general conformity to Elias' ideal cyclothem and recognized two cyclothems having similar lithologic and paleontologic characteristics: the Threemile and Schroyer cyclothems. As such, Hattin (1957) proposed the name Wreford Megacyclothem (Figure 18) to define those rock units extending from the upper portion of the Spieser Shale to the lower portion of the Wymore Shale.

Cyclic Sedimentation

The term cyclothem was first defined by Wanless and Weller (1932, p.1003) as a "...series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian Period." Cyclothems were considered as formations, composed of specific members, so they are lithostratigraphic units (North American Commission on Stratigraphic Nomenclature, 1983). Wanless and Weller (1932) postulated that these cyclothems represent cycles of sea-level change and that they are laterally extensive (at least basin-wide).

Moore (1936) accepted the definition of a cyclothem as the basic unit of lithostratigraphy, but he redefined cyclothems as limestone-shale couplets deposited during transgressive-regressive cycles. Moore (1936) regarded Wanless and Wellers' (1932) cyclothems as "megacyclothems" composed of up to five limestone-shale couplets. He considered each of these couplets to be a cyclothem, so megacyclothems were regarded as cycles of his cyclothems (i.e., cycles of limestone-shale couplets).

Heckel (1977) modified Moore's interpretation of the megacyclothem. He found that of the five limestone members recognized in a complete megacyclothem (referred to by Moore, 1936, as lower, middle, upper, super, and fifth), only the

middle and upper limestone members were present in most Missourian (Upper Pennsylvanian) cyclic sequences of Kansas. He therefore modified Moore's basic megacyclothem and termed the basic cycle of facies a "Kansas Cyclothem" (Figures 20 and 21). Each Kansas cyclothem contains five "members". They are, from bottom to top: an outside (nearshore) shale, a middle (transgressive) limestone, a core (offshore) shale, an upper (regressive) limestone, and an outside (nearshore) shale (Heckel, 1977). Heckel (1980) found that each Kansas cyclothem represents about 400,000 years. Those sections which did contain many of the limestones recognized by Moore (1936) promoted Heckel, et al. (1979) to define what they called "minor transgressive-regressive sequences" each having a periodicity of about 100,000 to 200,000 years. These "minor transgressive-regressive sequences", were regarded as uncommon features of the Pennsylvanian System of Kansas (Heckel, et al., 1979). More recently, Heckel (1986) cited the fact that complete, well developed Kansas cyclothems are only represented in certain Pennsylvanian intervals of certain geographic areas. Therefore, he proposed that such well developed Kansas cyclothems be referred to as "major cycles", that poorly developed Kansas cyclothems be referred to as "intermediate cycles", and that the minor transgressive-regressive sequences (as noted above) be referred to as "minor cycles". The extent and significance of such units is uncertain (i.e., see Busch, West, and

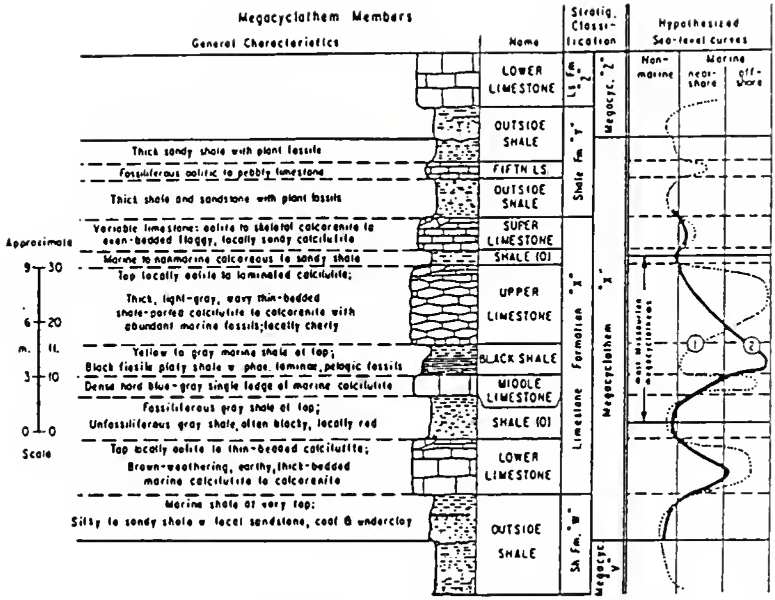


Figure 20. Typical Mid-Continent cyclothem showing various environmental interpretations (from Heckel and Baesemann, 1975). Dotted line (1) represents interpretation by Moore (1936) and the solid line (2) as interpreted by Heckel (1977)

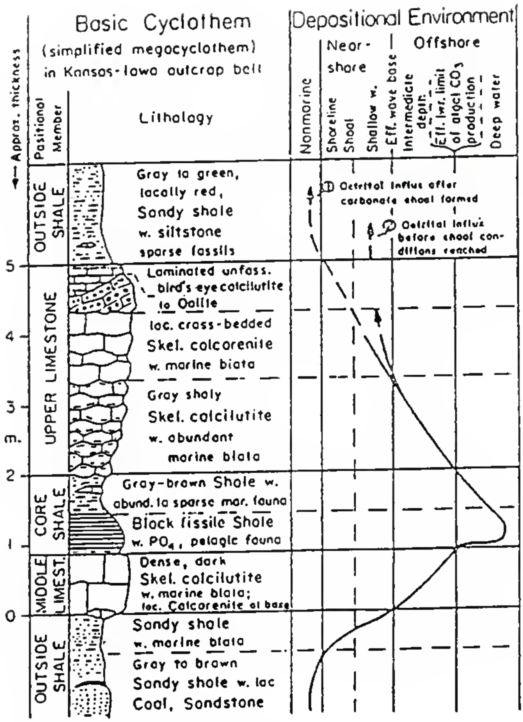


Figure 21. Heckel's basic Kansas cyclothem (modified from Heckel, 1977, p. 1047).

Rollins, 1987).

Anderson and Goodwin (1980), and Goodwin and Anderson (1985) have proposed that most sedimentary sequences are composed of small scale (1-5 meters thick) shallowing-upward units, which they termed "punctuated aggradational cycles", or PACs. As Goodwin and Anderson (1985, p.516) stated: "the hypothesis of Punctuated Aggradational Cycles (PACs) is a comprehenaive stratigraphic model which states that most stratigraphic accumulation occurs episodically as thin (1-5 meters thick) shallowing-upward cycles separated by sharply defined non-depositional surfaces". Geologically instantaneous, basin-wide, relative base-level rises (punctuation events) create these non-depositional surfaces (Goodwin and Anderson, 1985). The basic tenet of Anderson and Goodwin's PAC hypothesis is that the shallowing-upward motif, on the scale of a few meters of thickness, is pervasive throughout the stratigraphic record. They estimate the duration of PACs to be 5,000-100,000 years. PACs can also be grouped into larger-scale transgressive-regressive sequences, which Anderson and Goodwin (1980, 1985) regard as "shallowing PAC sequences".

Cyclic deposits of a much greater magnitude than those just discussed have also been studied. For example, Vail, et al. (1977) have defined global onlap-offlap patterns from seismic data. Their firat-, second-, and third-order "depositional" aequences have durations of 225-300 m.y.,

10-80 m.y., and 8-10 m.y. respectively and may have been caused by global cycles of sea-level change (Vail, et al., 1977).

According to Vail, et al. (1977, p. 83) "Two cycles of the first order, over 14 of the second order and approximately 80 of the third order are present in the Phanerozoic, not counting late Palezoic cyclothems." The transgressive apices (i.e., stillstands or maximum points) of the first-order depositional sequences are found in the Lower Ordovician and the Upper Cretaceous (Vail, et al., 1977). The regressive apex of one first-order depositional sequence is found in the Permo-Triassic, and sea level has been regressive (at this first-order scale) since the Late Cretaceous (Vail, et al., 1977).

All Permo-Carboniferous strata are included within two such second-order depositional sequences. Pennsylvanian and Lower Permian strata compose an entire aecond-order depositional sequence (Vail, et al., 1977); whereas middle-upper Permian strata are part of a superjacent second-order depositional sequence.

Through his work on unconformity bounded stratigraphic units, Chang (1975) introduced the terms synthem and interthem and described a synthem as a major stratigraphic unit that is bounded by regional disconformities or angular unconformities and is comparable in vertical magnitude with one or more chronostratigraphic systems. As such, a synthem

is equivalent to a second-order depositional sequence of Vail, et al. (1977). An interthem (Chang, 1975) is a minor stratigraphic unit that is bounded by local to regional disconformities and is comparable in vertical magnitude with a chronostratigraphic stage (or series). The interthem is, therefore, equivalent to the third-order depositional sequences of Vail, et al. (1977). Chang (1975) also suggested that the use of prefixes such as "sub" and "super" may be used if further ranks of classification are needed.

As a result of his studies in the Carboniferous of northwest Europe, and in an attempt to put order into the nomenclature of eustatic cycles, Ramsbottom (1979) proposed that a three stage hierarchal nomenclature be adopted when describing Carboniferous cycles of sedimentation. For his largest cyclic unit, he adopted the term synthem from Chang (1975). For the two smaller cyclic units he used the terms mesothem and cyclothem. Mesothems are of a smaller scale than Vail's third-order depositional sequence and have durations of 1.1-1.3 m.y. (Ramsbottom, 1979). Ramsbottom's cyclothems are the same scale as cyclothems of Wanless and Weller (1932) and Heckel (1977), megacyclothems of Moore (1936), and shallowing PAC sequences of Goodwin and Anderson (1985).

Hierarchy of Genetic Transgreaaive-Regreaaive Unita

Busch (1984) and Busch and Rollins (1984), from the analysis of the works listed and discussed in the previous section, have derived a hierarchy of time-stratigraphic transgressive-regressive (T-R for short) units that can be used to systematize Permo-Carboniferous sequences (Table 1). They noted that there is a physical, nested hierarchy of T-R units; however, the absolute durations of T-R units can be estimated, and they are also hierarchal. A total of six different scales of allocyclic T-R units (Busch and Rollins, 1984) have been recognized in the rock record. These six scales of T-R units have been split (Busch and Rollins, 1984) into two subdivisions; major T-R units and minor T-R units.

The three major scales of "depositional sequences" defined by Vail, et al., (1977) are considered as major T-R units by Busch and Rollins (1984). As such, they regarded these "depositional sequences" as first-, second-, and third-order T-R units. These T-R units have durations of 225-300 m.y., 20-90 m.y., and 7-13 m.y., respectively (Busch and West, 1987). The synthems of Chang (1975) and Ramsbottom (1979), and the second-order depositional sequences of Vail, *et al.*, (1977), are considered as second-order T-R units by Busch and Rollins (1984). Second-order T-R unita are bounded by major unconformities found within the first-order T-R units (Vail, *et al.*, 1977). According to Vail, *et al.* (1977)

HIERARCHY OF PERMO-CARBONIFEROUS T-R UNITS

BUSCH & ROLLINS, 1984 AND BUSCH, 1984	VAIL *et al.*, 1977	CHANG, 1975 AND RAMSBOTTOM, 1979	MOORE, 1936	GOODWIN AND ANDERSON, 1985	HECKEL, 1977 AND HECKEL, 1986	WANLESS AND WELLER, 1932
FIRST-ORDER 225-300 Ma	FIRST ORDER DEPOSITIONAL SEQUENCES					
SECOND-ORDER 20-90 Ma	SECOND ORDER DEPOSITIONAL SEQUENCES	SYNTHEMS				
THIRD-ORDER 7-13 Ma	THIRD ORDER DEPOSITIONAL SEQUENCES					
FOURTH-ORDER 0.6-3.6 Ma		MESOTHEMS				
FIFTH-ORDER 300-500 ka		CYCLOTHEMS	MEGACYCLOTHEMS	SHALLOWING PAC SEQUENCES	KANSAS CYCLOTHEMS; MAJOR CYCLES	CYCLOTHEMS
SIXTH-ORDER 50-130 ka			CYCLOTHEMS	PUNCTUATED AGGRADATIONAL CYCLES (PACs)	MINOR CYCLES	

Table 1. Hierarchy of Permo-Carboniferous T-R units after Busch and Rollins (1984) and Busch and West (1987).

these second-order T-R units represent unconformity-bounded onlap-offlap (retrogradational-progradational) sequences. Third-order T-R units are the largest units found within second-order T-R units. Unlike second-order T-R units, third-order T-R units can either be unconformity-bounded T-R units or T-R units with conformable contacts (Vail, et al., 1977; Busch and West, 1987).

Fourth-, fifth-, and sixth-order T-R units are collectively referred to as "minor" scales of T-R units (Busch and Rollins, 1984). As with the third-order T-R units, minor T-R units can be unconformity-bounded T-R units or T-R units with conformible contacts (Busch and West, 1987).

The largest of the minor T-R units is the fourth-order T-R unit. The average duration of a fourth-order T-R unit is 0.6-3.6 m.y. (Busch and West, 1987). The estimated duration of the fourth-order T-R units, however, may vary depending on the type of fourth-order units present. Busch and West (1987) describe two different types of fourth-order T-R units that they refer to as either type A, or type B. Where and how the boundaries of the fourth-order T-R unit are placed determines the type. In type A fourth-order T-R units the boundary is placed at the top of any fifth-order T-R unit having a transgressive apex of greater magnitude than the fifth-order T-R unit immediately above it (Busch and West, 1987). Ramsbottom (1979) recognized fourth-order T-R units

of this type in Carboniferous aequences of Europe and termed them mesothems. In contrast, the boundary for type B fourth-order T-R units is placed at the top of any fifth-order T-R unit having a transgressive apex of less magnitude than the fifth-order T-R unit immediately above it (Busch and West, 1987). Fourth-order T-R units of this type have been recognized in Permo-Carboniferous sequences of North America by Busch (1984) and West and Busch (1985). Busch (1984) and Heckel (1985,1986) found that late Pennsylvanian sequences of North America can only be subdivided using type B fourth-order T-R units.

Fifth-order T-R units (Table 1) are on the same scale as cyclothems of Wanless and Weller (1932), "Kansas cyclothems" (major and intermediate cycles) of Heckel (1977, 1986), megacyclothems of Moore (1936), and shallowing PAC sequences of Goodwin and Anderson (1985). Fifth-order T-R units have an average periodicity of about 300,000-500,000 years (Busch and West, 1987).

The smallest of the minor T-R units are sixth-order T-R units. These are the same scale (temporally and spatially) as Goodwin and Anderson's (1985) punctuated aggradational cycles (PACs). Sixth-order T-R units are best defined in exposures or cores by using the PAC approach set forth by Goodwin and Anderson (1985) and Goodwin, et al. (1986). Sixth-order T-R units have average periodicities on the order of tens-of-thousands of years (Busch and West, 1987). For

example, sixth-order T-R units, 2-3 meters thick, with periodicities of about 50 thousand years were found in the Carboniferous Seminula oolite of South Wales (Goodwin and Anderson, 1985). Permo-Carboniferous sixth-order T-R units with periodicities of 25-130 thousand years have been defined by West and Busch (1985), Busch, et al. (1985), Busch (1988), Bogina (1988), Clark (1988), Leonard (1988); Busch, Bogina, and Clark (1988); and Busch, Clark, and Bogina (1988).

Methoda Of Study

Detailed stratigraphic sections at 20 localities (Figure 22) in northeastern Kansas were measured using measuring tape and hand-held Brunton compass. To obtain more complete geographic distribution, information from an additional 13 stratigraphic sections (Figure 22) was obtained from Hattin (1957). Field observations included descriptions of lithology (color, composition, and texture), primary sedimentary structures, and fossil content. In addition to surface outcrop data, a core (Amoco #1 Hargrave) from northern Riley County was also described (see Appendix, p. 201).

Oriented samples of limestones, and bulk aamples of shales, were collected at all localities. Two key localities in particular, chosen for completeness and geographic

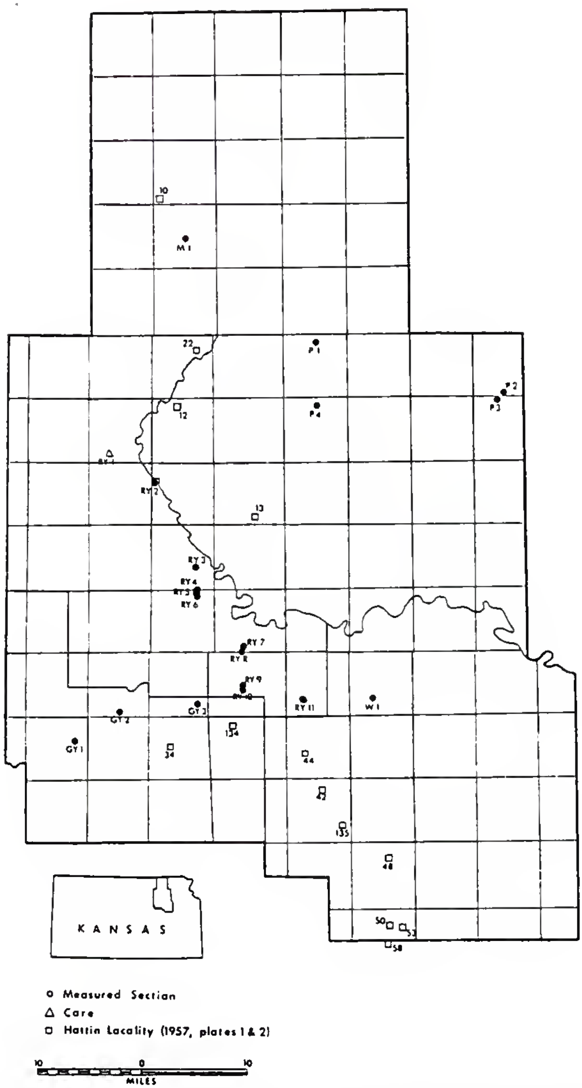


Figure 22. Map showing locations of measured sections. Those localities used in this investigation, measured by Hattin (1957, plates 1 and 2), are also shown.

position, were sampled in detail (every unit except the basal red claystone units) to get a thorough representation of the overall vertical sequence.

Lsboratory study consisted of preparation of thin-sections from limestones and the disaggregation of bulk shale samples. Eighty-three thin sections were examined using a polarizing petrographic microscope and classified according to the carbonate classification of Folk (1959; 1962). Fossiliferous shale samples were submerged in a Quaternary-0 solution for at least 10 days, or until the samples were disaggregated. Each day the solutions were agitated for approximately 10-15 minutes. The samples were then washed, seived (into 60, 140, and 200, mesh sizes), and dried. Fossils were separated from the matrix (for the 140 and 200 mesh sizes a binocular microscope was used) and identified to the genus, if possible. Those samples not thin sectioned or disaggregated were re-examined in the laboratory with either a hand-lens or binocular microscope (or both) to obtain more accurate lithologic and fossil descriptions.

The punctuated aggradational cycle (PAC) approach (following Goodwin and Anderson, 1985) was used for outcrop and core analysis. The PAC hypothesis states that most sedimentary sequences are composed of T-R units about 1 to 5 meters thick (Figure 23). These individual PACs are manifested as asymmetrical shallowing-upward units with a very thin, or even absent, transgressive base. They are

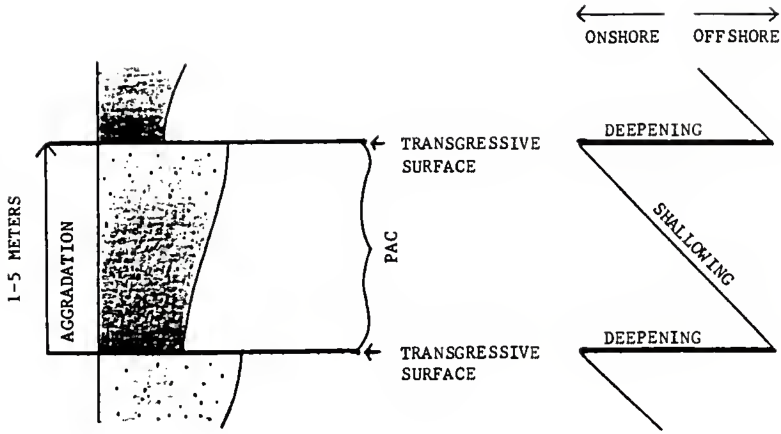


Figure 23. Punctuated aggradational cycle (PAC) concept (modified from Goodwin and Anderson, 1985, figure 1, p. 517).

separated by transgressive surfaces which represent a relative deepening of water. Geologically episodic transgression is inherent to the PAC hypothesis. Longer intervals of relative sea-level stasis, during which there is gradual aggradation and progradation, follow these relatively rapid minor sea-level rises (e.g., Goodwin and Anderson, 1985; Busch, 1984; Busch, et al. 1985; Busch, 1988). The transgressive events associated with PACs are assumed to be allogenic events of at least basin-wide extent (Goodwin and Anderson, 1985). PACs are sixth-order T-R units in the hierarchy of Busch and Rollins (1984) and Busch and West (1987). Goodwin and Anderson (1985) also grouped PACs into larger-scale transgressive-regressive sequences, or "shallowing PAC sequences" (i.e., fifth-order T-R units), which range from 5 to 30 meters thick (Figure 24). It should be noted, however, that PACs (sixth-order T-R units) and PAC sequences (fifth-order T-R units) differ from cyclothems or megacyclothems. In contrast to PACs and PAC sequences, cyclothems and megacyclothems are lithostratigraphic units composed of rhythmic or cyclic repetitions of specific lithofacies that do not necessarily have genetic boundaries or lateral persistence.

Genetic Surfaces.--Minor T-R units (i.e., sixth-, fifth-, and fourth-order T-R units) are regarded as the net result of climate change and associated glacio-eustatic sea level fluctuation (Busch and West, 1987). Therefore, genetic

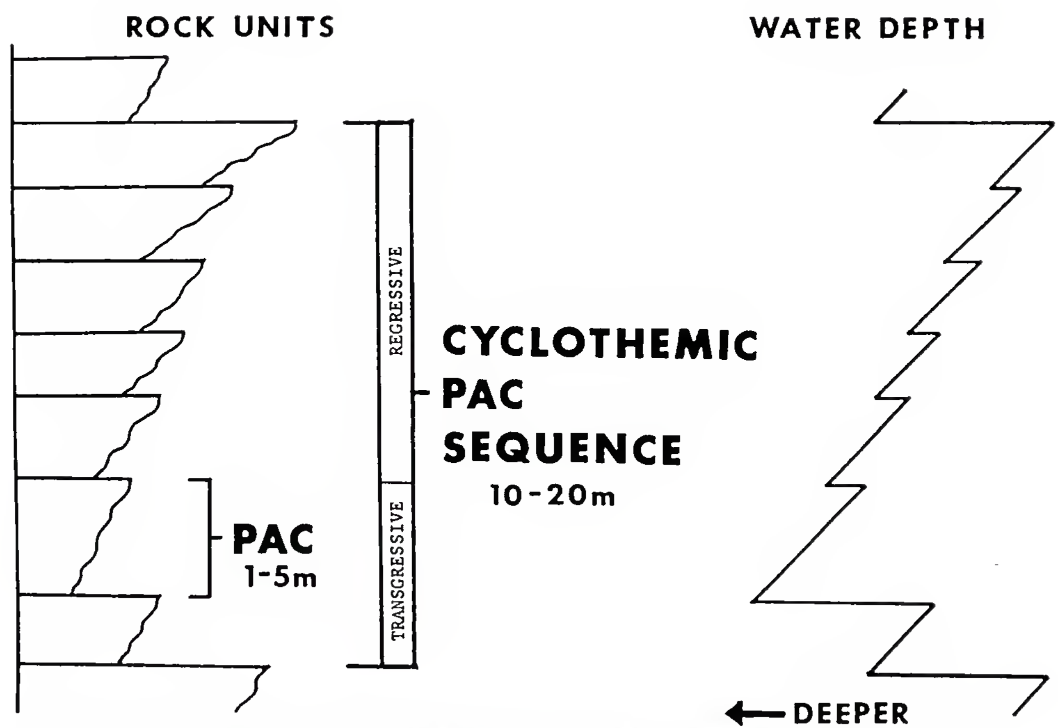


Figure 24. Concept of punctuated aggradational cycles, or PAC's, (sixth-order T-R units) and cyclothemic PAC sequences (fifth-order T-R units), modified from Anderson and Goodwin (1980).

surfaces between T-R units can be of two types: transgressive surfaces and climate change surfaces (Busch, 1984). Easiest to discern are the transgressive surfaces, which are simply defined as contacts between marine facies (i.e., facies containing marine fossils) and the subjacent nonmarine facies that were transgressed. Transgressive surfaces may be more cryptic, however, in intervals containing only marine facies. For these instances, transgressive surfaces are defined as contacts at which relatively deeper water (or more open marine) facies overlie a shallowing sequence of relatively shallower water facies. Climate change surfaces tend to be more cryptic than transgressive surfaces and are defined as contacts between nonmarine facies presumed to have formed under subaerial (often arid) conditions (e.g., paleosols or calcretes) and superjacent nonmarine facies presumed to have formed under more humid (possibly nonmarine subaqueous) conditions (e.g., coal or lacustrine limestones). These cryptic climate change surfaces were recognized by Somerville (1979) and Wright (1981) as prominent partings in the Early Carboniferous of Wales. The formation of these partings is attributed to emergence (i.e., regression) at the end of a transgressive-regressive episode of deposition (Somerville, 1979; Wright, 1981). Because of paleotopographic variations climate change surfaces may change laterally (in a seaward direction) into transgressive surfaces (Busch, 1984; Busch and Rollins, 1984; Busch and West, 1987).

Disjunct facies.-- Sedimentary facies are defined as any areally restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of other parts of the unit (Moore, 1949). For example, De Raaf, _et al_. (1965) subdivided a group of three formations (Lower Westphalian of North Devon) into a (cyclical) repetition of facies based on lithological, structural, and organic aspects detectable in the field. According to Walker (1984), subdivision of a rock body into constituent facies (or units of similar aspect) is a classification procedure, and the degree of subdivision is governed by the objectives of the study. After facies are defined, they are generally given an environmental interpretation. Walker (1984, p.1) stated, "...the key to interpretation is to analyze all of the facies communally, in context." Conceptualizing the relationship between the distribution of modern sedimentary environments and the distribution of sedimentary facies in rock sections is generally addressed by application of Walther's law. Walther's law, as translated by Middleton (1973, p. 979), stated: "It is a basic statement of far reaching significance that only those facies and facies-areas can be superimposed primarily which can be observed beside each other [i.e., are contiguous] at the present time." Therefore, surfaces between noncontiguous facies represent discontinuities across which Walther's law is invalid; that is, erosion or non-

depositional unconformities. Walther's law has usually been applied at the formational scale (e.g., Rickard, 1962; Laporte, 1969) using gradualistic lithostratigraphic models. In this genetic-stratigraphic investigation, however, the stratigraphic record is regarded as a stacked series of small-scale allogenically produced shallowing-upward units (i.e., sixth-order T-R units, or PACs), that are bounded by discontinuities (e.g., transgressive surfaces or climate change surfaces). The presence of disconformities at T-R unit boundaries invalidates the use of Walter's law except within the genetic T-R units (Goodwin, et al., 1986, p.424).

Goodwin, et al. (1986) stated that PACs (sixth-order T-R units) represent the net accumulation that occurs between punctuation events, which initiate and terminate deposition of the PAC. PAC boundaries represent punctuation events, and are abrupt facies changes to relatively deeper and environmentally disjunct facies. Within each PAC, facies change laterally and vertically in a generally gradual manner, but between PAC's facies are disjunct, indicating an abrupt (episodic?) environmental discontinuity. Thus, paleoenvironmental and paleogeographic analysis can be made for each individual PAC or sixth-order T-R unit (Goodwin et al., 1986).

Biofacies Analysis.--In analyzing the rocks of the Wreford Limestone Formation a number of factors, including

the fossil assemblages, were used in making paleoenvironmental interpretations. Each sixth-order T-R unit was divided into a number of distinct biofacies. Biofacies are regarded here as a distinct set of fossils within part of a sixth-order T-R unit that is recognizably different from other sets of fossils within that sixth-order T-R unit. As such, no biofacies crosses the genetic boundaries that separate sixth-order T-R units. However, the same types of biofacies may be found in a number of stratigraphic levels within different sixth-order T-R units. Paleoenvironmental interpretations for biofacies of this thesis were made based on the types of taxa found (e.g., eurytopic vs. stenotopic), their relative abundance, condition of the fossils (e.g., broken and abraded vs. whole articulated and in life position), and diversity.

Organisms characteristically respond to environmental changes. For example, Brezinski (1983) and Wells (1985) showed that different biofacies, responding to environmental stress gradients, are encounted seaward from paleoshoreline. In the Ames Limestone (Late Pennsylvanian, Missourian), Brezinski (1983) found four biofacies (Figure 25): a molluscan biofacies (nearshore); a Neochonetes biofacies (shallow open marine); a Composita-Neospirifer biofacies (relatively deep, most open marine); and a Crurithyris biofacies (shallow open marine). Wells (1985) found three biofacies in the Woods Run Limestone (Late Pennsylvanian): a

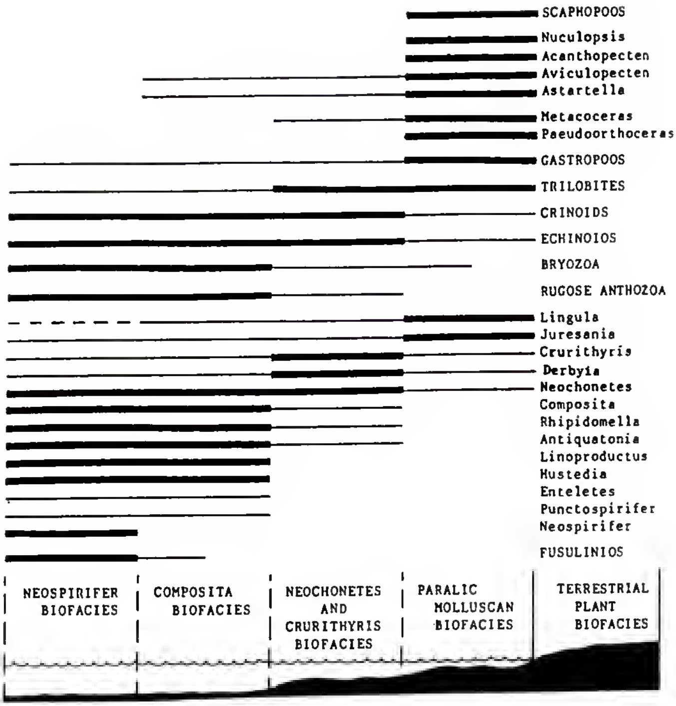


Figure 25. Biofacies of the Ames Limestone (Missourian or Early Virgilian?) of the Northern Appalachian Basin, as defined by Brezinsky (1981, 1983) and modified with data from Busch (1984).

Cavellina-rugosan-Glabrocingulum-echinoderm biofacies (shallow open marine), a Straparollus-Donaldina-Coryllites biofacies (shallow, nearshore environment: shallow subtidal or lagoon), and a Lingula-Orbiculoidea-Hollinella-bellerophontacean biofacies (very shallow nearshore environment: lagoonal, intertidal, or shallow subtidal). The general trends these studies show include a decrease and eventual disappearance of stenotopic organisms in a shoreward direction (e.g., Neospirifer, Composita, echinoids, bryozoa). On the other hand, relative abundance of eurytopic organisms (e.g., Lingula, Orbiculoidea, Aviculopecten, bellerphontaceans) increases in the shoreward direction. Thus, the presence (and relative abundance) or absence of stenotopic or eurytopic organisms may be used in a general sense to make environmental interpretations.

The terms abundant, common, sparse, and rare were used in outcrop and laboratory analysis to indicate the relative number of specimens (of a particular fossil) within a rock unit or sample. The term abundant refers to fossils that are numerous enough to be readily seen in fresh outcrop surface, hand sample, or washed sample. Common refers to fossils that are numerous but not abundant enough to be immediately conspicuous in the sample or outcrop. The term sparse applies to fossils that are very poorly represented in the sample or outcrop. Rare refers to fossils of which only one or two specimens can be found in the sample or outcrop after close

examination.

Diversity was an important factor used in making paleoenvironmental interpretations. Diversity is defined as the taxonomic richness of a community (Raup and Stanley, 1975). In this study the relative diversity for a particular biofacies was determined by counting the number of genera found. Bretsky and Lorenz (1970) showed that in modern marine faunas there is an increase in diversity from nearshore, shallow-water, unstable environments to offshore, deeper-water areas which have a high degree of environmental stability. This same general trend of increased diversity offshore from regions of environmental instability has been documented in the Ordovician and Devonian by Bretsky (1970), Walker and Laporte (1970), Sutton, et al.(1970), and in the Middle and Late Pennsylvanian by Stevens (1971) and Donahue and Rollins (1974). This change in species diversity as a result of environmental stability supports the "stability-time" hypothesis of Sanders (1969). As interpreted by Donahue and Rollins (1974, p.154), "...the longer lasting or more stable the environment is, the more diverse will be its fauna. Thus, species diversity varies directly with environmental stability." According to Donahue and Rollins (1974), in transgressive-regressive sequences the stillstand (i.e., transgressive apex) indicates the time of maximum stability, when species are biologically accomodated, and an increase in species interactions and

number of species occurs. In this study then, stillstand (maximum transgression, or transgressive apex) is represented by that unit which contains the biofacies with the highest diversity (most genera). One exception to this general trend occurs were highly diverse molluscan-dominated biofacies are encountered. Molluscan-dominated communities are generally indicative of nearshore environments (Bretsky 1969; Anderson 1971). This anomalous diversity increase in the nearshore direction is termed a "molluscan reversal" by Dodin (1974).

In summary, according to the above information, nearshore very shallow water communities are generally characterized by low diversity and occurrence of almost solely eurytopic organisms. Open marine communities, are generally represented by high (maximum) generic diversity with both stenotopic and eurytopic organisms present.

Information derived from examination of each biofacies, using the criteria discussed above, was used to construct a relative sea-level curve for the detailed measured sections. Biofacies analysis was also instrumental in locating and defining disjunct facies and transgressive surfaces within the Wreford Limestone Formation.

<u>Definition and Labelling of T-R units.</u>--The way in which sixth- and fifth-order T-R units are defined and labeled is schematically depicted in Figure 26. There are nine sixth-order genetic surfaces bounding eight complete sixth-order T-R units and parts of two others. Each of these surfaces

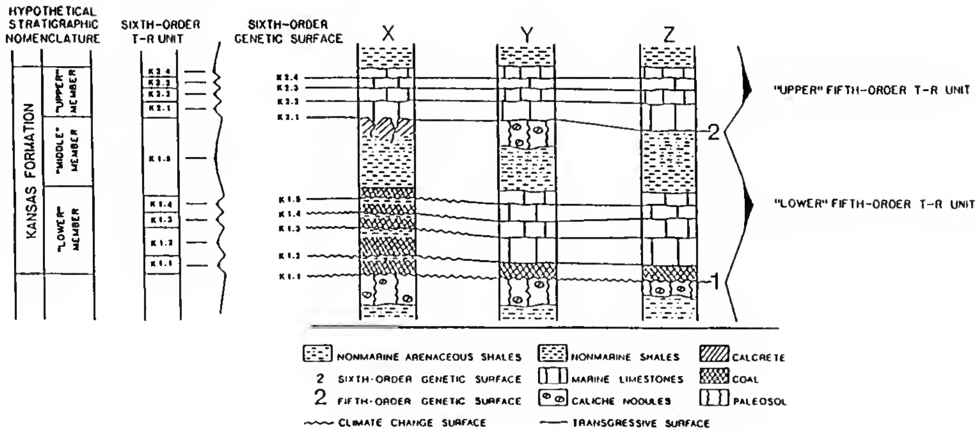


Figure 26. Schematic illustration of three hypothetical locations (X, Y, and Z) to exemplify the relationship between climate change surfaces and transgreasive surfaces plus definition and labeling of sixth- and fifth-order T-R units (modified from Busch and West, 1987, p. 148). See text for discussion.

has been labeled using a three part system in the form Kn.n . The first letter (i.e., K) is derived from the first letter in the name of the formation within which the genetic surface is found. The first "n" indicates, in numerical sequence, the fifth-order T-R unit in which the genetic surface is found. The second "n" (separated from the first by a decimal point) indicates, in numerical sequence from base to top, which sixth-order genetic surface it is within the fifth-order T-R unit. For example, "K 2.3" indicates that this genetic surface is the third (3) sixth-order genetic surface within the second (2) fifth-order T-R unit found within the hypothetical Kansas (K) Formation. Exceptions to this might be seen for those genetic surfaces found just above or below a formation. For example K1.1 is not within the Kansas Formation, however the K is used because this genetic surface is a part of a fifth-order T-R unit (discussed below) the majority of which is found within the Kanaas Formation. Sixth-order T-R units are named for the sixth-order genetic surfaces which form their lower boundaries. For example, T-R unit K2.3 is the T-R unit between genetic surfaces K2.3 and K2.4.

Fifth-order genetic surfaces can be identified by examining the relative magnitudes of the marine facies within each sixth-order T-R unit. A fifth-order genetic surface is placed at the base of any sixth-order T-R unit that shows a more pronounced transgression (thicker and more widespread

marine, or more humid nonmarine, facies) than the sixth-order T-R unit below it. For example, the hypothetical facies (Figure 26) below genetic surface K1.1 at all localities consists of nonmarine arenaceous shales and paleosols. The hypothetical facies (Figure 26) within sixth-order T-R unit K1.1 at all localitites consists of coal marking the climate change that initiated a new fifth-order T-R unit. Therefore K1.1 is both a sixth- and a fifth-order genetic surface. The marine facies in sixth-order T-R unit K2.1 are thicker and more widespread than those of sixth-order T-R unit K1.5. Therefore sixth-order genetic surface K2.1 is also a fifth-order genetic surface. The sixth-order T-R unit with the best developed marine facies within a fifth-order T-R unit is also the apex of transgression for that fifth-order T-R unit. The fifth-order T-R units are named for that formation or member which contains the best developed marine facies within the fifth-order T-R unit (e.g., the "Lower" fifth-order T-R unit and "Upper" fifth-order T-R unit in Figure 26). Therefore, in this study the fifth-order T-R units will be named for the two dominant marine members: the Threemile Limestone (Threemile fifth-order T-R unit) and the Schroyer Limestone (Schroyer fifth-order T-R unit). The Schroyer fifth-order T-R unit was previously defined by Busch, et al. (1985) and redefined by Busch (1988).

HIERARCHAL GENETIC STRATIGRAPHY OF THE WREFORD FORMATION

Two sections, picked for completeness and geographic location, were studied in detail. One is locality GY3: NW1/4, SE1/4, sec. 25, T. 11 S.,R. 7 E., in northeastern Geary County, Kansas (Figure 22). The second is a composite section from localities RY4, RY5, and RY6 in the general vicinity of sec. 2, T. 10 S., R. 7 E., southeastern Riley County, Kansas (Figure 22). Samples were collected from every unit except the basal rooted, red claystone units in each section and were closely analyzed in the laboratory. In addition to the lithology and sedimentary structures, the relative number and types of fossils found in each unit were identified and listed.

Ten of the fourteen limestone units in the section at locality GY3 were thin-sectioned. For the thicker limestones (e.g., units 14, 17, 18, and 27, Figure 27) up to four thin sections were analyzed to determine whether any significant fossil or lithologic changes were present within the unit, which might not be visible macroscopically. Any cryptic lithologic or fossil changes found were then checked for lateral continuity by close examination (i.e., thin sections or close examination with a binocular microscope) of the same unit at other localities. All limestone samples from both sections were also slabbed and examined using a binocular

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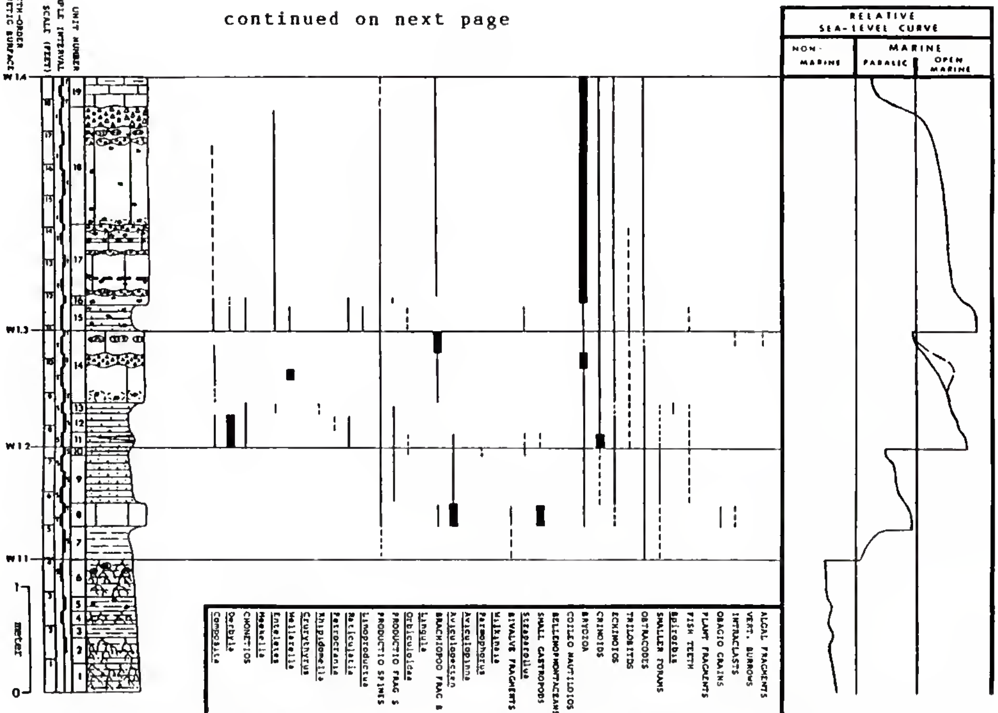
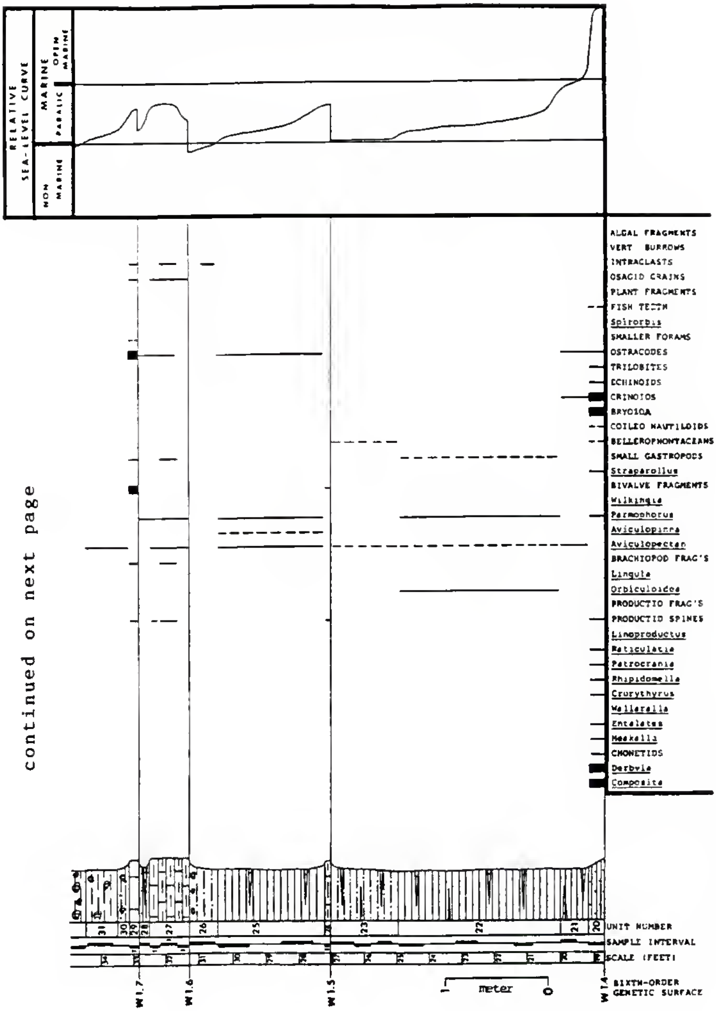


Figure 27. Detailed section at locality GY3 showing lithostratigraphic relationships, fossil content, and relative sea-level curve.



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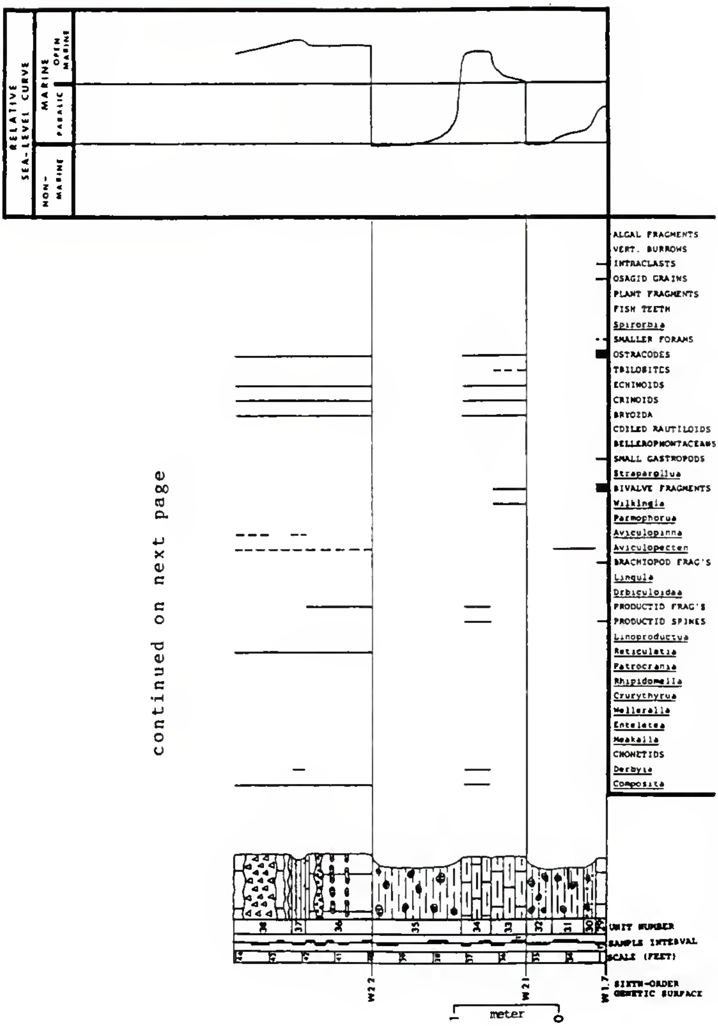

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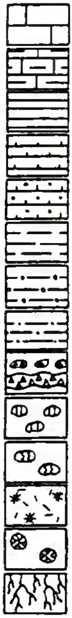

Limestone

Argillaceous limestone

Shale

Calcareous shale

Silty, calcareous shale

Claystone

Sandy claystone

Silty claystone or siltstone

Chert (nodular and bedded)

Calcareous nodules

Gypsum

Rectangular and rosette crystal molds

Geodes

Root mottles

T - next to a sample indicates that sample was thin-sectioned

S - next to a sample indicates that sample was disaggregated and the residue examined

- indicates that a fossil is abundant

- indicates that a fossil is sparse to common

- indicates that a fossil is rare

Figure 27 continued. Explanation

microscope.

Samples (shale, siltstone, and claystone) were disaggregated when the unit bounded a possible genetic surface (e.g., units 6, and 7, Figure 27) or when the exact positioning of a genetic surface was in question (e.g., units 9 thru 13, Figure 27). For example, the calcareous shale between units 8 and 14 (Figure 27) was sampled approximately every 3 to 5 inches. Each sample was disaggregated and the residue examined, this helped delineate units 9, 10, 11, and 12 (Figure 27) and also the genetic surface (W1.2) between units 10 and 11.

Analysis of lithologies, sedimentary structures, and fossils in the two sections studied in detail revealed microlithofacies and biofacies, that are indicative of specific paleoenvironments. The vertical relationships of these paleoenvironmental interpretations indicate that each interval is composed of small-scale (0.3 m to 2.5 m) T-R units that generally shallow-upward and are separated by transgressive surfaces (sixth-order T-R units or PACs). Each genetic surface is labeled as noted in the methods portion of this paper (see Figure 26), with each label beginning with the letter W (i.e., Wreford Formation). Each sixth-order T-R unit is then named for the genetic surface forming its lower boundary. The two sections studied in this detailed manner are discussed below. Full descriptions of all measured sections can be found in the Appendix.

Locality GY3, northerneastern Geary County.--Based on field observations, lithostratigraphic analysis, and fossil assembages, the study interval at locality GY3 contains nine sixth-order genetic surfaces (W1.1 through W2.2) bounding all or parts of ten sixth-order T-R units (Figure 27). These sixth-order T-R units comprise one complete fifth-order T-R unit, here disignated as the "Threemile fifth-order T-R unit", and the lower portion of a superjacent fifth-order T-R unit (the Schroyer fifth-order T-R unit, Busch *et al.*, 1985). The lowermost portion of the measured section (below sixth-order genetic surface W1.1, Figure 27) represents the uppermost portion of a fifth-order T-R unit subjacent to the Threemile fifth-order T-R unit (i.e., the "Funston fifth-order T-R unit").

From 0 to 0.82 m (genetic surface W1.1) above the base of the measured section is a series of siliciclastic claystones and silty claystones (Figure 27). These claystones are generally red in color and have abundant root traces and mottles, microslickensides, and occasional granule- to pebble-sized calcareous nodules. They are continental deposits (i.e., rooted alluvium, or fluvent paleosols) formed during maximum marine regression associated with final development of the top of the Funston fifth-order T-R unit.

Unit W1.1--The firat aixth-order T-R unit, W1.1, is present from 1.19 m (surface W1.1) to 2.23 m (aurface W1.2) from the base of the measured aection (Figure 27). The lower 0.30 m (unit 7) of T-R unit W1.1 consists of sparsely fossiliferous (ostracodal) claystone. This is overlain by 0.22 m (unit 8) of fossiliferous (molluscan dominant) calcarenite containing occasional "Osagia" coated shell fragments and rare, amall (up to 0.3 cm) claystone intraclasts. Above this limestone is 0.44 m of sparsely fossiliferous silty calcareous shale (unit 9). The uppermost 0.1 m (unit 10) of T-R unit W1.1 consists of silty calcareous shale that is also sparsely fossiliferous, with Orbiculoidea and Aviculopecten the dominant organisms.

Thus from base to top, sixth-order T-R unit W1.1 shows an initial introduction (in unit 7) of marine fossils at the base (indicating transgression over continental deposits below) with fossil content and diversity then increasing into the limestone (unit 8). A total of 10 different taxa were found in unit 8 (Figure 27). While diversity is essentially unchanged density decreases in the overlying calcareous shales (units 9 and 10). At the top of unit W1.1 diversity increases slightly, with a total of 11 taxa found in unit 10 (Figure 27). This increase in taxa is attributed to the appearance of a number of eurytopic organisms including Orbiculoidea, Permopherous, and Straparollus. In addition, sieve analysis of the calcareous shale (unit 10) may have

yielded a better representation of the total number of taxa than did thin-section analysis of unit 8. There is also an increase in ailiclastic input going upward from unit 8 to units 9 and 10. Paleoenvironments within sixth-order T-R unit W1.1 are interpreted as ranging from very shallow (possibly brackish) water (e.g., upper intertidal mudflats or lagoons) at the base; to shallow, relatively more open marine (e.g., lower intertidal) in the limestone (unit 8); to a relatively more shallow (possibly brackish) water environment (e.g., upper intertidal) at the top. Unit 8 is the transgressive apex.

Unit W1.2--The second sixth-order T-R unit (W1.2) is found from 2.23 m (surface W1.2) to 3.30 m (surface W1.3) above the base of the measured section (Figure 27). At the base of sixth-order T-R unit W1.2 is 0.15 m (unit 11) of very calcareous shale containing common argillaceous limestone lenses. Unit 11 is very fossiliferous with a diverse fauna dominated by brachiopods, crinoids, echinoids, and bryozoans. A total of 15 taxa were found in unit 11 (Figure 27). Most specimens are robust in form and articulated. Above this unit is 0.17 m of shale (unit 12) that is slightly less calcareous than unit 11. Although slightly less fossiliferous (12 taxa), unit 12 contains an abundant, diverse fauna dominated by the same organisms as in unit 11, with crinoids being somewhat less prevalent and smaller in size. This is overlain by 0.1 m of sparsely fossiliferous,

calcareous shale (unit 13) with sparse brachiopods, crinoids, bryozoans and Spirorbis.

The top 0.34 m of T-R unit W1.2 is a cherty fossiliferous limestone. The chert layers (Figure 27) found in the unit have fossil contents identical to the surrounding limestone. Thin section analysis of unit 14 revealed several changes in texture and fossil content within the unit. The lower 0.1 to 0.13 m of unit 14 is a fossiliferous calcilutite, with aparse to common fragments of brachiopods, bryozoans, crinoids, echinoids, and ostracodes. This lower part also contains abundant rectangular gypsum crystal molds and is slightly argillaceous. The middle portion (approximately 0.41 m) of unit 14 is a coarse calcilutite containing common to abundant, fragmented and articulated shells of bryozoa, brachiopods, crinoids, and echinoids. Pellets are common in the matrix and occasionally fill the interiors of articulated shells. Whole articulated specimens of Composita and Wellerella are common in this middle part. The upper 0.1 to 0.13 m of unit 14 is a slightly argillaceous fine calcarenite containing common fragments of brachiopods, bryozoans, and echinoids with sparse crinoids. Also found in the upper part of unit 14 are rare to sparse algal fragments and small (up to 0.1 in.) micritic intraclasts. The number of taxa in unit 14 ranges from 8 at the base to 9 in the middle back to 7 at the top.

In summary, upward through sixth-order T-R unit W1.2

fossil content and diversity decrease, with 15 taxa found at the base (unit 11) and 7 at the top (top of unit 14). The number of articulated specimens and the size of some organisms (e.g., crinoids) decreases upward through units 11, 12, and 13. Grain size increases upward through unit 14 accompanied by the appearance of algal fragments and intraclasts at the top. Paleoenvironmentally, the high diversity and abundance of fossils, in addition to the presence of delicate marine organisms such as slender branching bryozoans, indicates an open marine environment of normal salinity (Newton, 1971; Cuffey, 1967) at the base of sixth-order T-R unit W1.2 . Newton (1971, p.10) estimated a depth of between 40 and 50 ft. (9-15m) for Wreford units containing this biofacies. This open marine environment grades into a relatively shallower environment (e.g., intertidal) at the top.

The appearance of abundant articulated _Wellerella_ and _Composita_ in the middle part of unit 14 indicates the presence of a deepening event approximately 0.13 m above the base of unit 14. Further investigation at other localities indicates however, that this deepening event is autocyclic in nature, possibly due to topographic variation in the area of investigation.

Unit W1.3--The third sixth-order T-R unit, W1.3, can be found 3.3 m (surface W1.3) to 5.7 m (surface W1.4) from the base of the measured section. The lower 0.23 m (unit 15) of

this T-R unit is a very calcareous shale with an abundant highly diverse fossil assemblage dominated by brachiopods, bryozoans, crinoids, and echinoids (Figure 27). A total of 15 taxa were found in unit 15, eight of which are brachiopods. Many of the specimens are robust and articulated. This unit is overlain by 0.09 m of argillaceous limestone (unit 16). Unit 16 is slightly less fossiliferous than the underlying shale but the same basic fossils dominate. Above unit 16 is 0.66 m of fossiliferous coarse calcilutite (unit 17) with four layers (three bedded, and one nodular, Figure 27) of white to dark gray and dark blue-gray chert. Fossil content of the chert and surrounding limestone is identical. Above unit 17 is 1.12 m of fossiliferous, massive, chalky (powdery texture on a fresh broken surface) calcilutite (unit 18). Two layers (one bedded, one nodular) of chert occur in the upper part of this limestone (Figure 27). Between these chert layers the limestone is occasionally gypsiferous and contains scattered chert nodules. Fossil content of the chert is identical to that of the surrounding limestone, both being dominated by bryozoans and brachiopods. Some organisms (e.g., Composita) are absent at the top, and the amount of fragmented shell debris increases, so that the top of the limestone is a calcarenite. The uppermost bed (unit 19) in sixth-order T-R unit W1.3 is a fossiliferous calcarenite. This limestone consists mostly of abraded (subangular to subrounded) fragments of bryozoans,

brachiopod shells, crinoids, and echinoids. Grain-size increases from a fine calcarenite basally, to a coarae calcarenite at the top.

In summary, upward through sixth-order T-R unit W1.3 fossil content and diversity decrease, with 15 taxa at the base (unit 15) and only 6 at the top (unit 19), and grain size (matrix of fragmented and abraded shell debris) increases. Paleoenvironments within this aixth-order T-R unit become more restricted (less normal marine) upwards, with open marine at the base grading into less normal marine (e.g., intertidal) at the top.

Unit W1.4--Sixth-order T-R unit W1.4 is present from 5.7 m (surface W1.4) to 8.25 m (surface W1.5) above the base of the section (Figure 27). The basal 0.15 m of T-R unit W1.4 is a very fossiliferous, calcareous shale (unit 20). Unit 20 contains the highest diversity of any unit in the study interval, with 18 taxa, nine of which are brachiopods. The assemblage is dominated by large (robust) forms of bryozoans, brachiopods, crinoids, and echinoids. Above unit 20 is 0.25 m of fossiliferous (Aviculopecten and very small crinoids dominant) ahale (unit 21) followed by 1.52 m of very sparsely fossiliferous shale (unit 22) containing common horizontal burrows (Chondrites) and thin limestone lenses. The top of T-R unit W1.4 consists of 0.64 m of very aparsely fossiliferous silty claystone (unit 23) with occasional thin limestone lenses.

Thus, from base to top, this aixth-order T-R unit shows a dramatic decrease in fossil abundance and diversity, a decrease in carbonate content, and an increase in coarser siliciclastic content (as seen in the silty claystone at top). Sixth-order T-R unit W1.5 is interpreted to have been deposited in paleoenvironments ranging from open marine at the base to more restricted, shallow (possibly brackish) environments (e.g., upper intertidal mudflat or lagoon) at the top.

Unit W1.5--Sixth-order T-R unit W1.5 is found from 8.25 m (surface W1.5) to 9.39 m (surface W1.6) above the base of the section (Figure 27). At the base of T-R unit W1.5 is 0.05 m of fossiliferous, argillaceous calcilutite (unit 24) with productid brachiopods and bivalves. Above unit 24 is 0.81 m of sparsely fossiliferous shale (unit 25) containing occasional thin lenses of limestone, bivalves, and ostracodes. The top 0.25 m (unit 26) of sixth-order T-R unit W1.5 is silty claystone containing sparse angular limestone intraclasts (up to 0.03 m in width), found mainly at the base, and a caliche-like zone of calcareous nodules at the top.

In summary, upward through sixth-order T-R unit W1.5 there is a slight decrease and eventual loss of marine invertebrate macrofossils and a change from sediments of definite marine origin to sediments with characteristics of nonmarine origin (e.g., caliche-like zone in unit 26).

Paleoenvironments within this sixth-order T-R unit range from ahallow (restricted) marine (e.g., shallow intertidal) at the base to supratidal (possibly nearshore coastal plain) at the top.

Unit W1.6--The next sixth-order T-R unit, W1.6, is present from 9.39 m (surface W1.6) to 9.88 m above the base of the measured section (Figure 27). The basal 0.38 m (unit 27) of this T-R unit consists of fossiliferous calcilutite, that is slightly argillaceous. Thin-section analysis shows that the middle part (approximately 0.2 m) of unit 27 is more fossiliferous (than either the base or top) and contains intraclasts, which are absent in the base or top of the unit (Figure 27). Unit 27 is overlain by 0.1 m of very sparsely fossiliferous shale (unit 28) containing occasional, very thin (up to 0.3 cm) lenses of powdery calcareous clay.

In summary, sixth-order T-R unit W1.6 shows an initial increase (in the lower 0.1 m of unit 27), and a subsequent decrease, in fossil abundance and diversity up through the T-R unit. There is also a decrease in carbonate content toward the top of T-R unit W1.6. Sixth-order T-R unit W1.6 probably repreaents paleoenvironments ranging from shallow intertidal at the base; to a relatively restricted marine (e.g., lower intertidal) setting in the middle; to a relatively more restricted environment (e.g., upper intertidal) at the top.

Unit W1.7--The seventh sixth-order T-R unit, labeled W1.7, is found from 9.88 m (surface W1.7) to 10.59 m (surface W2.1) above the base of the section (Figure 29). The lower 0.1 m (unit 29) of T-R unit W1.7 is a fossiliferous coarse calcilutite with occasional large (up to cobble-sized) algal (*Osagia*?) coated limestone intraclasts. These intraclasts are found mostly at the top of unit 29. Above unit 29 is 0.11 m of sparsely fossiliferous claystone (unit 30) containing sparse to common lenses of sand- to granule-sized particles (of both siliciclastic and carbonate composition). Occasionally calcareous nodules occur in unit 30. Above unit 30 is 0.29 m of sparsely fossiliferous claystone (unit 31) containing sparse irregularly shaped calcareous nodules and occasional horizontal burrows (*Chondrites*?). The top 0.23 m of T-R unit W1.7 is a non-fossiliferous silty claystone (unit 32) containing abundant irregularly shaped caliche nodules. This nodular caliche contains abundant vugs and pockets of claystone with common collapse structures.

In summary, upward through sixth-order T-R unit W1.7 there is a decrease and eventual loss of marine taxa, a general increase in siliciclastic input, and an increase in irregularly shaped nodular caliche. Sixth-order T-R unit W1.7 is interpreted to have been deposited in paleoenvironments ranging from lower intertidal at the base through supratidal (possibly sabkha-like) at the top.

Unit W2.1--The eighth sixth-order T-R unit, labeled W2.1, found in this section is from 10.59 m (surface W2.1) to 12.16 m (surface W2.2) above the base of the aection (Figure 27). The basal part of T-R unit W2.1 is 0.33 m of slightly argillaceous, fossiliferous calcilutite (unit 33). This basal unit is overlain by 0.28 m of coarse calcilutite (unit 34) that is also fossiliferous and argillaceous. Fossil content and diversity is greater in unit 34 than in unit 33. Seven taxa are represented in unit 33, with eight taxa in unit 34, three of which are brachiopods (Composita, Derbyia, and productid fragments). The upper 0.84 m of T-R unit W2.1 is a non-fossiliferous claystone (unit 35) with caliche nodules and calcite geodes.

Changes which occur from base to top of sixth-order T-R unit W2.1 include a decrease in marine invertebrates, an increase in siliciclastic debris, and an increase in nodular caliche. Sixth-order T-R unit W2.1 probably represents paleoenvironments ranging from shallow (relatively more restricted) subtidal at the base, to open (relatively normal) marine, through supratidal at the top.

Unit W2.2--The remainder of this measured section comprises the lower portion of a tenth sixth-order T-R unit (T-R unit W2.2). The base of sixth-order T-R unit W2.2 is located 12.16 m (surface W2.2) above the base of the section. The lower 0.62 m of T-R unit W2.2 is a fossiliferous coarse calcilutite (unit 36) containing three layers of chert (one

bedded, two nodular, Figure 29). Both chert and limestone have identical fossil contents, the dominant organisms being brachiopods, bryozoans, crinoids, and echinoids. Unit 36 is overlain by 0.1 m of very calcareous, fossiliferous shale (unit 37). At the top of the section is 0.53 m of fossiliferous calcarenite (unit 38) with two layers of bedded chert (Figure 27). Again, fossil content is the same for both chert and limestone. Paleoenvironmentally, all three units in the lower portion of sixth-order T-R unit W2.2 represent open marine environments.

Description Summary.--The sixth-order T-R units just described comprise one complete, and parts of two other, fifth-order T-R units. The facies below sixth-order T-R unit W1.1 (units 1 thru 6) include nonmarine claystones, siltstones, and paleosols at the top of the uppermost sixth-order T-R unit in the Funston fifth-order T-R unit. Sixth-order T-R unit W1.1 (with the occurance of marine units; e.g., unit 7 Figure 27) marks the start of transgression of the Threemile fifth-order T-R unit. Therefore, sixth-order genetic surface W1.1 is also a fifth-order genetic surface. The relative magnitude of the marine facies developed at the transgressive apex of sixth-order T-R unit W2.1 is noticably greater than the magnitude of the marine facies developed at the transgressive apex in sixth-order T-R unit W1.7 (Figure 27). Therefore, sixth-order genetic surface W2.1 ia also a fifth-order genetic surface. These two genetic surfaces form

the lower (W1.1) and upper (W2.1) boundriea of the Threemile fifth-order T-R unit. These two genetic surfacea (W1.1 and W2.1) also form the upper boundary of the Funaton fifth-order T-R unit and the lower boundry of the Schroyer fifth-order T-R unit respectively.

Sixth-order T-R unit W1.4 contains the best developed (i.e., thickest and most open marine biofacies) marine facies in the Threemile fifth-order T-R unit. The greatest diversity of any unit in the section, including 18 taxa, occurs in unit 20 at the base of W1.4. In addition, unit 20 contains the greatest diversity of brachiopods of any unit in the section. Nine brachiopod genera, including <u>Composita</u>, <u>Derbyia</u>, <u>Neochonetes</u>, <u>Enteletes</u>, <u>Meekella</u>, <u>Crurithyris</u>, <u>Rhipidomella</u>, <u>Reticulatia</u>, and <u>Petrocrania</u> occur in unit 20. As such, sixth-order T-R unit W1.4 also includes the apex of transgression (unit 20, Figure 27) for the Threemile fifth-order T-R unit. That portion of the section above genetic surface W2.1 (sixth-order T-R units W2.1 and W2.2) comprises the lower portion of the Schroyer fifth-order T-R unit.

Detailed fossil relationships, based on disaggregated sample, thin section, and split sample analysis, as well as lithostratigraphic relationships and relative sea-level curves are given for detailed section GY3 in Figure 27. Note that in most of the sixth-order T-R units the number of marine taxa decreaaes from bottom to top of the aixth-order T-R unit. Exceptions to this occur only at the base (e.g.,

W1.1 and W2.1) and at the top (e.g., W1.6) of the fifth-order T-R units.

Composite Section at localities RY4, RY5, and RY6

Detailed fossil data, from disaggregated samples, thin sections, and split samples, as well as lithostratigraphic relationships and relative sea-level curves, are given in Figure 28 for the composite detailed section at localities RY4, RY5, and RY6. The study interval at these localities contains nine sixth-order genetic surfaces (W1.1 through W2.2, Figure 28) bounding all, or parts of, ten sixth-order T-R units. These sixth-order T-R units comprise one complete fifth-order T-R unit (the Threemile fifth-order T-R unit) and the lower portion of a superjacent fifth-order T-R unit (the Schroyer fifth-order T-R unit). The lowermost portion of the measured section, below sixth-order genetic surface W1.1 (Figure 28), represents the uppermost portion of a fifth-order T-R unit subjacent to the Threemile fifth-order T-R unit (the Funston fifth-order T-R unit).

From 0 to 0.84 m (surface W1.1) above the base of the section is a series of siliciclastic claystones (Figure 28). These non-fossiliferous claystones (units 1 through 3) are greenish gray and red-gray in color and contain sparse (at bottom) to abundant (at top) root traces and mottles. The upper portion of unit 3 contains common calcareous nodules. These units are interpreted as continental deposits (i.e., rooted alluvium, or fluvent paleosol) formed during maximum

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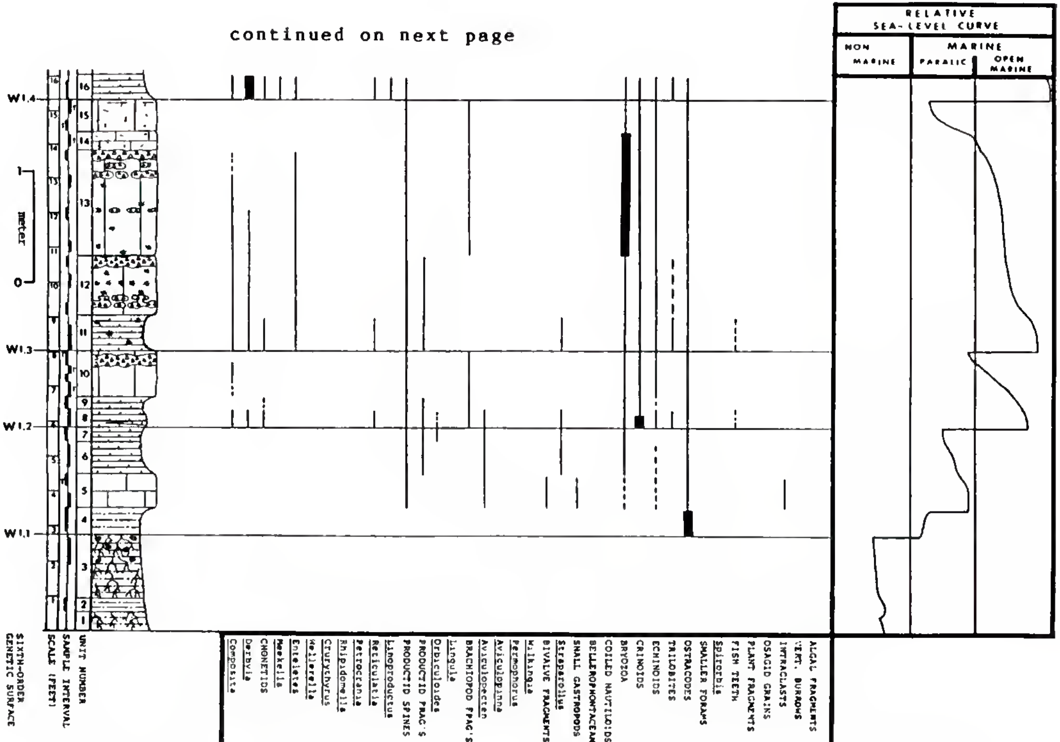

Figure 28. Composite detailed section from localities RY4, RY5, and RY6 showing lithostratigraphic relationshipa, foaail content, and relative sea-level curve. Explanation same as for figure 27.

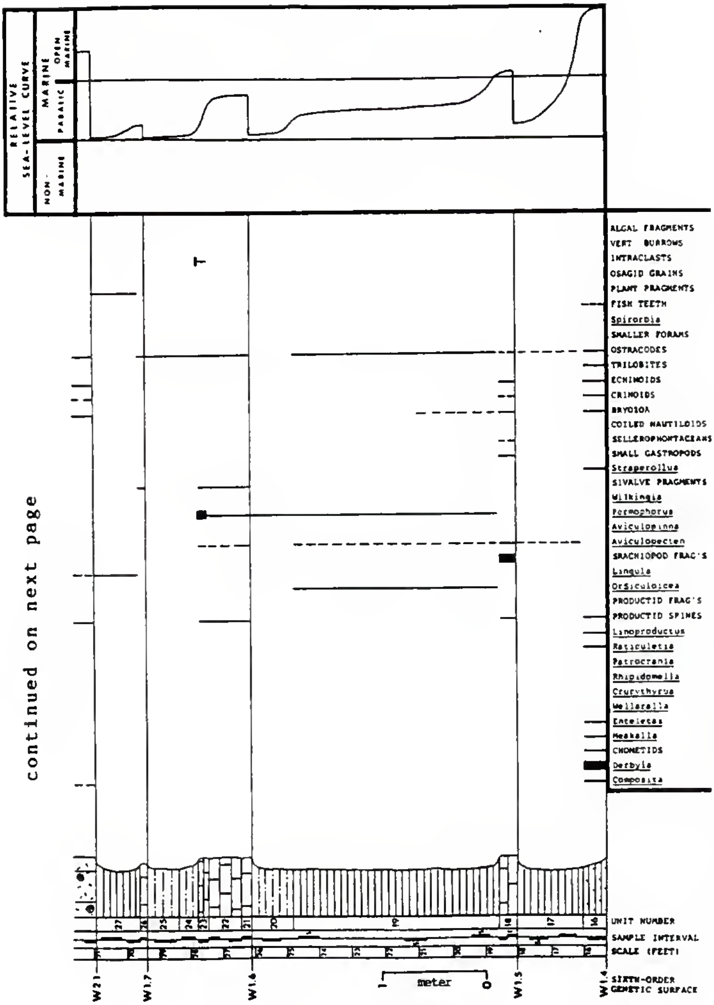

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Figure 28 continued.

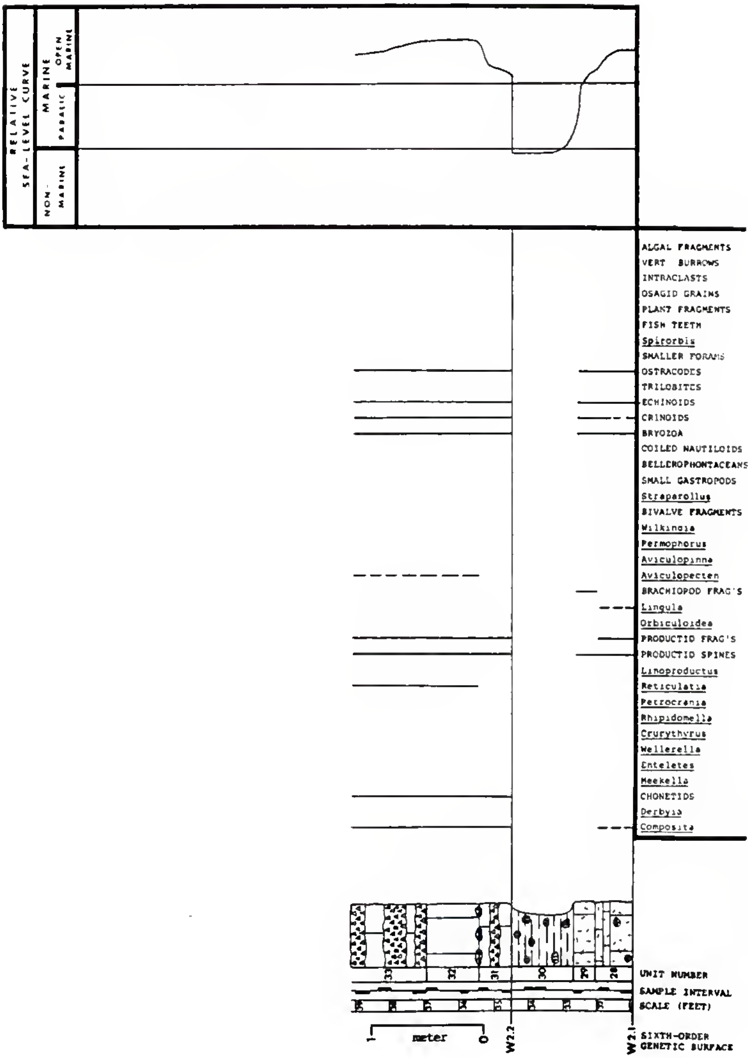

Figure 28 continued.

marine regreasion and progradation associated with final development of the Funston fifth-order T-R unit.

Unit W1.1--The first sixth-order T-R unit, W1.1, is present from 0.84 m (surface W1.1) to 1.78 m (aurface W1.2) above the base of the section (Figure 28). The base of sixth-order T-R unit W1.1 consists of 0.24 m of silty claystone (unit 4) containing abundant ostracodes. Above unit 4 is 0.30 m of foasiliferous (molluscan dominant) calcarenite (unit 5) containing sparse, small (up to 0.3 cm) limestone intraclasts. This is overlain by 0.28 m of fossiliferous calcareous shale (unit 6). The top of T-R unit W1.1 consists of 0.13 m of sparsely fossiliferous calcareous shale (unit 7) with Orbiculoidea and Aviculopecten the dominant organisms.

Thus, upward through sixth-order T-R unit W1.1 there is an initial increase in fossil abundance and diversity from unit 4 to unit 5, with a subsequent decrease from unit 5 to the top of the T-R unit. Units 5, 6, and 7, each contain six taxa. However, eurytopic organisms (e.g., Orbiculoidea and Aviculopecten) become more abundant toward the top of T-R unit W1.1. Paleoenvironments within this sixth-order T-R unit (W1.1) are interpreted as ranging from very shallow intertidal (e.g., upper intertidal mudflats or lagoons) at the base; to relatively more open marine (e.g., lower intertidal or shallow subtidal); back to a relatively more restricted (e.g., upper intertidal) environment at the top.

<u>Unit W1.2</u>--The second sixth-order T-R unit, W1.2, occurs from 1.78 m (surface W1.2) to 2.45 m (surface W1.3) above the base of the section. The lower 0.18 m of aixth-order T-R unit W1.2 is a highly fossiliferous calcareous shale (unit 8). Eleven taxa occur in unit 8, four of which are brachiopods. Dominant organisms in unit 8 include brachiopods, bryozoans, crinoids, and echinoids (Figure 28). Fossils become less abundant toward the top of the unit. Unit 8 is overlain by 0.10 m of sparsely fossiliferous calcareous ahale (unit 9) forming the top of T-R unit W1.2. Some of the organisms (e.g., chonetida and crinoids) in unit 9 are amaller in size than those found in unit 8. The top 0.41 m of T-R unit W1.2 is a cherty, fossiliferous fine calcarenite. A 0.10 m layer of bedded chert, light gray to dark gray in color, is located 0.25 m above the base of the unit. Fossil content of the chert and limestone is the same. Thin section and slab analyais showed that faunal and textural changes occur in unit 10. The lower 0.13 m of unit 10 is finer-grained (calcilutite) and less fossiliferous than the middle part of the limestone. The dominant organisms, including fragmented bryozoans, brachiopods, crinoids, and echinoids, are more abundant in the middle and upper parts of the unit. The upper 0.05 m of unit 10 is slightly argillaceous and contains rare amall (up to 0.3 cm) limestone intraclasts. Seven taxa occur in the lower and middle parts of the limestone and six at the top.

In summary, upward through aixth-order T-R unit W1.2 there ia a notable decrease in fossil abundance and diversity, with eleven taxa at the base (unit 8) and six at the top (top of unit 10). Grain-size increases upward through unit 10 accompanied by the appearance of intraclasts at the top. Paleoenvironments within this sixth-order T-R unit are interpreted as ranging from open marine (subtidal) at the base to a relatively more restricted environment (e.g., intertidal) at the top.

Unit W1.3--Sixth-order T-R unit W1.3 is found from 2.45 m (surface W1.3) to 4.67 m (surface W1.4) from the base of the section (Figure 28). At the base of sixth-order T-R unit W1.3 is 0.33 m of very fossiliferous, calcareous shale (unit 11). The upper 0.13 m of this shale is more calcareous and slightly less fossiliferous than the lower 0.18 m. Twelve taxa occur in unit 11. Dominant organisms include large (robust) and commonly articulated specimena of brachiopods, bryozoans, crinoids, and echinoids. Many of the brachiopods are in life position. Directly above the shale is 0.52 m of fossiliferous coarse calcilutite (unit 12). Unit 12 contains two layers of chert (Figure 28): one nodular, 0.10 m above the base, and one bedded at the top. Fossils in the chert are the same as those in the limestone. Within this limestone is a conspicuous 0.05 m zone of abundant rosette crystal molds of gypsum (approximately 0.25 m above the base) many of which are filled with chert. Unit 12 is overlain by

0.94 m of massive, chalky (powdery texture on a fresh broken surface), fossiliferous coarse calcilutite (unit 13) containing abundant fragments of fenestrate bryozoans. Grain-size increases upward through unit 13, changing from a coarse calcilutite at the base to a calcarenite at the top. Three layers of nodular chert and one layer of bedded chert can be found in the upper half of the limestone (Figure 28). Again, fossils are indentical in both chert and limestone. Above unit 13 is 0.18 m of fossiliferous calcarenite (unit 14) with common, horizontally elongate, solution pits. All fossils in unit 14 are fragmented, and many show signs of abrasion. The top of sixth-order T-R unit W1.3 is 0.28 m of massive, fossiliferous calcarenite (unit 15), which has the same basic characteristics as unit 14 except that it is more mottled in appearance, is slightly less fossiliferous, and the upper half is slightly argillaceous.

In summary, upward through sixth-order T-R unit W1.3 there is a decrease in fossil abundance and diversity and an increase in the amount of fragmented (and abraded) shell debris. Twelve taxa were found in unit 11 at the base of W1.3 and only four taxa at the top (unit 15). Sixth-order T-R unit W1.3 is interpreted to have been deposited in paleoenvironments ranging from open marine (subtidal) at the base to a relatively more shallow (possibly higher energy) environment (e.g., lower to upper intertidal) at the top.

Unit W1.4--The fourth sixth-order T-R unit, W1.4, is

present from 4.67 m (surface W1.4) to 5.50 m (surface W1.5) above the base of the section (Figure 28). The lower 0.23 m of T-R unit W1.4 is a very fossiliferous, calcareoua shale (unit 16) with the same basic fossil content as units 8 and 11, but unit 16 contains the highest number of taxa (14) found in any unit in this section, half of which are brachiopods. These include: Composita, Derbyia, Neochonetes, Meekella, Enteletes, Reticulatia, and Linoproductus. The dominant organisms (brachiopods, crinoids, bryozoans, and echinoids) are robust and the brachiopods are commonly articulated and in life position. This calcareous shale is overlain by 0.61 m of dark gray, sparsely fossiliferous (Aviculopecten) shale (unit 17) with common horizontal burrows (Chondrites).

Trends upward through sixth-order T-R unit W1.4 include a marked decrease in fossil abundance and diversity, accompanied by a slight decrease in carbonate content in the shales. Sixth-order T-R unit W1.4 probably represents paleoenvironments ranging from open marine at the base, to a relatively more restricted (shallower) environment (e.g., upper intertidal mudflat or lagoon) at the top.

Unit W1.5--Sixth-order T-R unit W1.5 ia found 5.50 m (surface W1.5) to 7.95 m (surface W1.6) above the base of the section (Figure 28). The basal 0.18 m of this T-R unit is a thinly bedded, very fossiliferous calcirudite (unit 18). Nine taxa occur in this limestone which is slightly

argillaceous and contains abundant Aviculopecten and common amall gastropods. Above unit 18 is 1.91 m of mottled (olive green with dark gray), sparsely fossiliferous shale (unit 19) with common to sparse horizontal burrows (Chondrites). The top of sixth-order T-R unit W1.5 0.41 m of very sparsely fossiliferous silty claystone (unit 20) with sparse horizontal burrows.

Thus, from base to top, sixth-order T-R unit W1.5 shows a decrease in fossil abundance and diversity (9 taxa in unit 18 and 1 taxa in unit 20), accompanied by a decrease in carbonate content and an increase in siliciclastic material. Paleoenvironments are interpreted to have ranged from a shallow nearshore (e.g., very shallow subtidal or lower intertidal) environment at the base, to a relatively more restricted (shallower) environment (e.g., upper intertidal) at the top.

Unit W1.6--The next sixth-order T-R unit, W1.6, occurs from 7.95 m (surface W1.6) to 8.97 m (surface W1.7) above the base of the section (Figure 28). The lower 0.10 m of this T-R unit is a chalky, fossiliferous (Permophorus and Aviculopecten dominant) coarse calcilutite (unit 21). Four taxa occur in unit 21. Above unit 21 is 0.32 m of chalky, thinly bedded, fossiliferous calcilutite (unit 22) with aparse horizontal burrows. This calcilutite is overlain by 0.10 m of fossiliferous (Permophorus dominant) calcirudite containing common dark gray to medium gray shale intraclasts.

The top 1.3 cm of this calcirudite is composed almost entirely of elongate, flat, pebble-sized ahale intraclasts. The top of sixth-order T-R unit W1.6 conaista of 0.48 m of sparsely fossiliferous (ostracodal), greenish-gray, silty claystone with sparse lenses (less thin 0.6 cm) of white to light yellowish gray, powdery, calcilutite. This silty claystone becomes less fossiliferous toward the top, accompanied by a slight increase in the thin lenses of calcilutite.

Upward trends within aixth-order T-R unit W1.6 include a decrease in fossil abundance and diversity, the appearance of intraclasts in the upper portion of the limestones, and an increase in siliciclastic material. This sixth-order T-R unit was probably deposited in paleoenvironments ranging from a shallow (relatively restricted) marine environment (e.g., lower intertidal) at the base, to relatively more restricted (e.g., upper intertidal to aupratidal) environments at the top.

Unit W1.7--The seventh sixth-order T-R unit, W1.7, occurs from 8.97 m (surface W1.7) to 9.42 m (surface W2.1) above the base of the section (Figure 28). At the base of T-R unit W1.7 is 0.10 m of sparsely fossiliferous calcilutite (unit 26). Above unit 26, forming the top 0.43 m of sixth-order T-R unit W1.7, is a sparsely fossiliferous (*Lingula*), greenish gray ahale containing sparse plant fragments.

In summary, from base to top, this sixth-order T-R unit

shows a decrease in marine invertebrate fossil diversity and abundance, and an increase in plant fossila accompanied by an increase in siliclastic material. Paleoenvironments for this sixth-order T-R unit are interpreted as ranging from a relatively restricted shallow environment (e.g., lower intertidal), to a relatively more restricted very shallow environment (e.g., upper intertidal) at the top.

Unit W2.1--The eighth sixth-order T-R unit, W2.1, at this locality is from 9.42 m (surface W2.1) to 10.52 m above the base of the section (Figure 28). The basal 0.34 m of T-R unit W2.1 is a fossiliferous (brachiopods, crinoids, bryozoans, and echinoids) coarse calcilutite (unit 28) containing common calcite geodes in a zone 0.08 m from the base. Seven taxa were found in unit 28, three of which are brachiopods (Composita, productid fragments, and Lingula). The upper 0.13 m of unit 28 is very thinly bedded and the lower part is more massive. Above unit 28 is 0.23 m of massive, fossiliferous, fine calcarenite (unit 29). The upper 0.10 m of unit 29 is slightly cherty. The top of T-R unit W2.1 consists of 0.56 m of non-fossiliferous claystone (unit 30) in which caliche nodules and geodes are common to abundant.

In summary, upward through sixth-order T-R unit W2.1 there is a decrease and eventual loss of marine taxa accompanied by an increase in siliciclastic material and calcareous nodules. Upward through the limestones (units 28

and 29) there is an increase in grain size. Sixth-order T-R unit W2.1 is interpreted to have been deposited in paleoenvironments ranging from shallow open marine (e.g., subtidal) at the base, to supratidal at the top.

Unit W2.2--The remainder of the measured section comprises the lower portion of a tenth sixth-order T-R unit (T-R unit W2.2). The base of sixth-order T-R unit W2.2 is located 10.52 m (surface W2.2) above the base of the section (Figure 28). The lower 0.28 m of T-R unit W2.2 is a massive, cherty, fossiliferous fine calcarenite (unit 31). This limestone contains two zones of chert: one bedded layer 0.10 m from the base, and one nodular at the top of the unit (Figure 28). Fossils in both chert and limestone are identical. The top 1.14 m (units 32 and 33) of the section is a massive, fossiliferous, fine calcarenite. The lower 0.46 m (unit 32) is chalky (powdery on a fresh broken surface) with common small vugs. There are three layers of bedded chert in the upper 0.67 m (unit 33) of the measured section (Figure 28). Again, fossil content is the same for both chert and limestone. These limestones (units 31 to 33) are interpreted to have been deposited in open marine, subtidal paleoenvironments.

Description Summary.--The sixth-order T-R units described above comprise one complete, and parts of two other, fifth-order T-R units. The facies below sixth-order T-R unit W1.1 (units 1 thru 3) are nonmarine silty claystones

and paleosols at the top of the uppermost sixth-order T-R unit in the Funston fifth-order T-R unit. The development of marine sediments (i.e., units 4 and 5) in sixth-order T-R unit W1.1 marks the start of transgression in the Threemile fifth-order T-R unit. Therefore, sixth-order genetic surface W1.1 is also a fifth-order genetic surface. The relative magnitude of the marine facies developed in sixth-order T-R unit W2.1 is noticably greater than the magnitude of the marine facies developed in sixth-order T-R unit W1.7 (Figures 27 and 28). Therefore, sixth-order genetic surface W2.1 is also a fifth-order genetic surface. These two genetic surfaces, W1.1 and W2.1, form the lower (W1.1) and upper (W2.1) boundaries of the Threemile fifth-order T-R unit. These two surfaces (W1.1 and W2.1) also form the upper boundary of the Funston fifth-order T-R unit and the lower boundary of the Schroyer fifth-order T-R unit respectively.

Sixth-order T-R unit W1.4 is the best developed marine facies in the Threemile fifth-order T-R unit. Fourteen taxa occur in unit 16 at the base of W1.4. This is the greatest number of taxa (genera) found in any of the units in the measured section. Seven of the fourteen taxa are represented by brachiopods, including: Composita, Derbyia, Neochonetes, Meekella, Enteletes, Reticulatia, and Linoproductus. As such, sixth-order T-R unit W1.4 is the apex of transgression (unit 16, Figure 28) for the Threemile fifth-order T-R unit. That part of the measured section

above genetic surface W2.1 (aixth-order T-R units W2.1 and W2.2) is the lower part of the Schroyer fifth-order T-R unit.

Note that in nearly all of the sixth-order T-R units faunal diversity decreases upward. An exception to this is sixth-order T-R units W1.1 which has a thin transgressive part at its base. Above this transgressive base, however, faunal diversity decreases upward toward the top of the T-R unit.

Correlation Methods and Results

Correlation between the two detailed sections (and eventually all other measured sections) was initially accomplished by aligning the sections relative to the Schroyer cherty limestone marker bed (sixth-order T-R unit W2.2) and the Threemile cherty limestone marker beds (sixth-order T-R units W1.2 and W1.3). The relative number of sixth-order T-R units and the general shape of the relative sea-level curves were then matched. The same number of sixth-order T-R units (i.e., six) are present between sixth-order T-R units W1.2 and W2.2 at all localities where the complete section is exposed. Other, less obvious, marker beds such as the: (1) very fossiliferous calcareous shales at the base of sixth-order T-R units W1.2, W1.3, and W1.4; (2) the molluscan limestone in W1.1; (3) the molluscan

(Aviculopecten rich) limestone at the base of sixth-order T-R unit W1.5; (4) the fossiliferous calcilutite at the base of sixth-order T-R unit W2.1; (5) and the red paleosol just below sixth-order T-R unit W1.1 were recognized and aided in substantiating the sixth-order correlations. A cross-section (Figure 29) oriented east-west illustrates the results of this correlation. After all of the measured sections are correlated, "micro-marker beds" are then identifiable. For example, in the southeastern portion of the study area (Figure 29) there is a thin (0.08 m to 0.20 m) zone of abundant Wellerella in sixth-order T-R unit W1.2. The potential of this Wellerella zone as a marker bed was first recognized by Hattin (1957). Brief descriptions of the marker beds mentioned above, and their relative stratigraphic positions, are given in Figure 30.

This correlation of the allocyclic sixth-order T-R units among all the measured aection in the study area made it possible to accurately define paleogeographic changes on a aixth-order scale.

Standard Hierarchal Genetic Stratigraphy of the Wreford

The standard stratigraphic section of that portion of the Wreford Formation examined here (i.e., from the upper part of the Speiser Shale to the middle part of the Schroyer

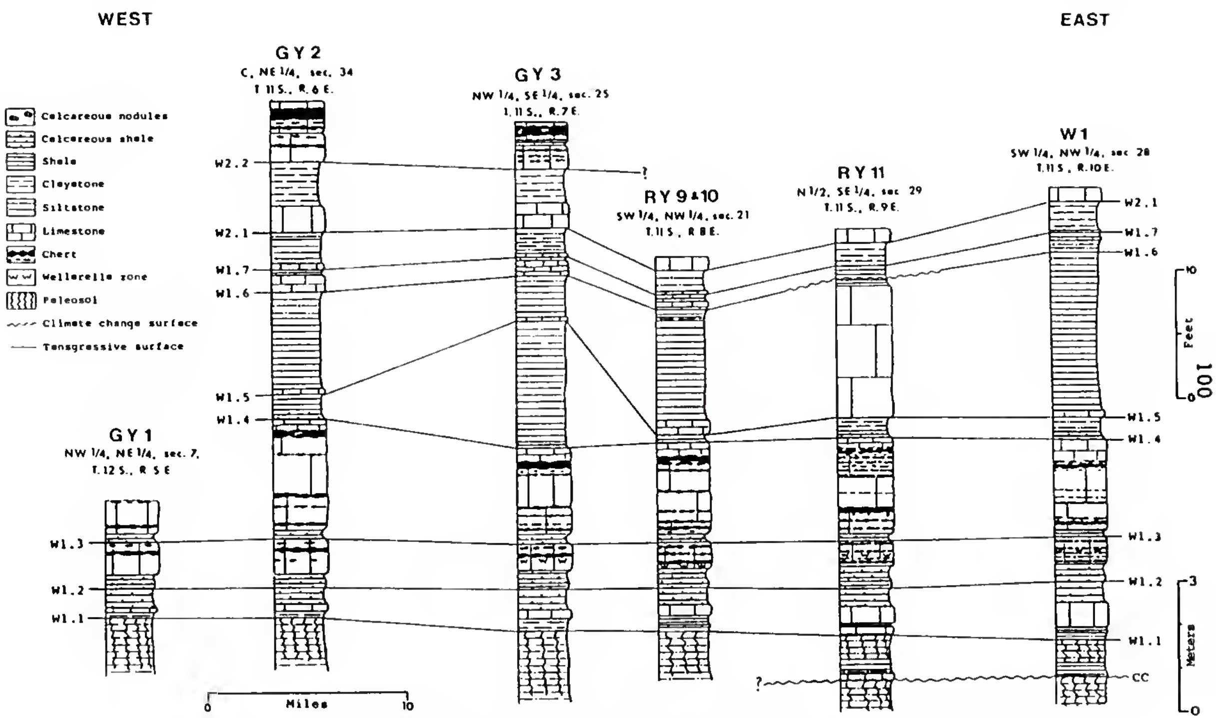

Figure 29. Cross-section of localities along Interstate Highway 70, showing correlation of sixth-order T-R units.

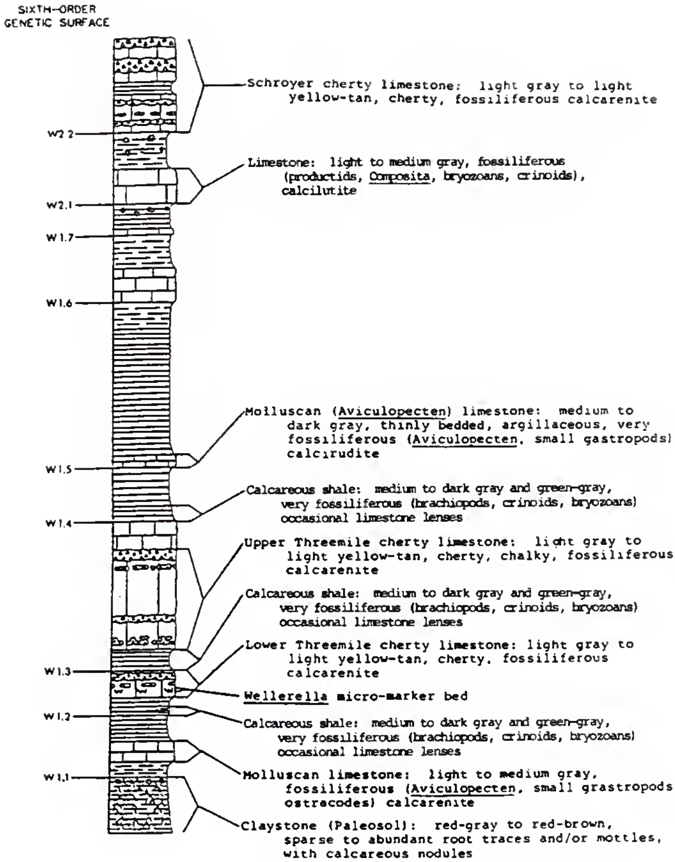

Figure 30. Diagram showing relative stratigraphic position and brief description of marker beds utilized in this study.

Limestone) contains nine aixth-order genetic aurfaces (W1.1 through W2.2) bounding all, or parts of, ten aixth-order T-R unita (Figure 31). These sixth-order T-R unita comprise one complete fifth-order T-R unit (the Threemile fifth-order T-R unit) and the lower part of a superjacent fifth-order T-R unit (the Schroyer fifth-order T-R unit). The faciea below sixth-order T-R unit W1.1 at all localitites include nonmarine claystones, siltstones, lacustrine limestones, and paleosols at the top of the uppermost sixth-order T-R unit (or several sixth-order T-R unita) in the Funston fifth-order T-R unit. These continental deposits were formed during maximum marine regression associated with final development of the top of the Funston fifth-order T-R unit.

In all measured sections the initial transgression for the Threemile fifth-order T-R unit is indicated by the presence of an ostracode rich, green-gray claystone (at the base of sixth-order T-R unit W1.1) lying directly on top of a green-gray to red paleosol. The Threemile fifth-order T-R unit has an average thickness of approximately 10 m and consists of seven sixth-order T-R units (W1.1 thru W1.8). The thickness of these sixth-order T-R units ranges from 0.27 m to 2.5 m. If the average periodicity of fifth-order T-R units is 300,000 to 500,000 years (Busch and West, 1987) then the sixth-order T-R units of the Threemile fifth-order T-R unit represent intervals of about 43,000 to 71,000 years.

Sixth-order T-R units W1.1 through W1.4 are composed of

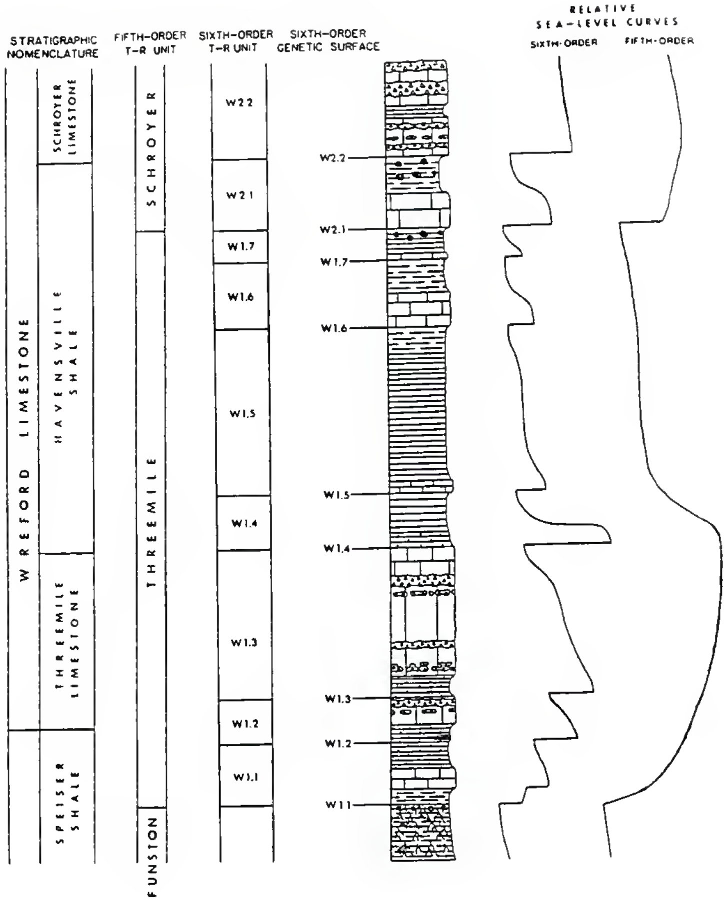

Figure 31. Illustration of standard hierarchal genetic stratigraphy of the Wreford Limestone.

a series of successively greater trangressiona forming the Threemile fifth-order transgressive sequence. Sixth-order T-R unit W1.4 (at all localities) has the beat developed (i.e., thickest and most open marine fossil association) marine facies in the Threemile fifth-order T-R unit. As auch, sixth-order T-R unit W1.4 also includes the apex of transgression for the Threemile fifth-order T-R unit. Sixth-order T-R units W1.5 through W1.7 compose a series of successively less extensive trangreasions that form the Threemile fifth-order regressive sequence.

The relative magnitude of the marine transgression in sixth-order T-R unit W2.1 is greater than the relative magnitude of the marine transgression in sixth-order T-R unit W1.7. This increase in the relative magnitude of marine transgression (back to open marine conditions) in sixth-order T-R unit W2.1 marks the initial transgression of the Schroyer fifth-order T-R unit. Therefore, sixth-order genetic aurface W2.1 is both the upper boundary of the Threemile fifth-order T-R unit and the lower boundary of the Schroyer fifth-order T-R unit. Above sixth-order T-R unit W2.1 is a series of fossiliferous (open marine) cherty limestone units which represent the lower part of the second sixth-order T-R unit (W2.2) in the Schroyer fifth-order T-R unit. This uppermost sixth-order T-R unit (sixth-order T-R unit W2.2) is equivalent to sixth-order T-R unit 7 in the Schroyer fifth-order T-R unit of Busch, et al. (1985) and sixth-order T-R

unit 8 of Busch (1988).

Information presented in the previous sections of this thesis clearly illustrates that the part of the Wreford Limestone Formation studied (i.e., from the upper part of the Speiser Shale to the middle part of the Schroyer Limestone) is composed of a series of thin (0.27 m to 2.5 m) transgressive-regressive units that are aeparated by genetic surfaces (i.e., transgressive or climate change) found between environmentally disjunct facies. For the most part, these T-R units shallow upward (i.e., are asymmetrical), as illustrated in Figures 27 and 28. Exceptions to this, occur in the lower (e.g., sixth-order T-R units W1.1, and W2.1, Figures 27 and 28) and upper (e.g., sixth-order T-R unit W1.6, Figure 27) parts of the fifth-order T-R units, where a thin transgressive unit occurs at the base of some sixth-order T-R units. This conforms quite well to the Hypothesis of Punctuated Aggradational Cycles (Goodwin and Anderson, 1985) which states that most statigraphic accumulation occurs episodically as thin (1-5 m. thick) shallowing-upward transgressive-regressive units separated by sharply defined non-depositional surfaces. Thus, the sixth-order T-R units found in the measured sections of this study, can also be considered as PACs. The PAC hypothesis (Goodwin and Anderson, 1985) predicts that these units are laterally extensive (allocyclic). Correlation of the measured sections in this study, shows that the constituent, small-scale T-R

units (PACs) are correlative over at least a 2,000 square mile area.

Comparison of Results with a Cyclothem Approach

Cursory analysis of the study interval (i.e., from the upper Speiser Shale to the middle Schroyer Limestone) in terms of a cyclothem approach (i.e., after Heckel, 1977, 1986) is presented in Figure 32. Many of the lithologic units ascribed to a typical "Kansas cyclothem" (Heckel, 1977) can be recognized in the Wreford Limestone and the subjacent Speiser Shale. For example, those rock units composing the Threemile fifth-order T-R unit (i.e., from the upper Speiser Shale to the upper Havensville Shale), might be subdivided into the following units: 1) nearshore to terrestrial noncarbonate strata (i.e., upper Speiser Shale); 2) a thin, transgressive limestone (i.e., lower Threemile cherty limestone); 3) a thin, offshore shale (i.e., fossiliferous, calcareous shale just above genetic surface W1.3, Figure 32); 4) a thicker, regressive limestone (i.e., upper Threemile cherty limestone); and 5) nearshore to terrestrial noncarbonate strata (i.e., lower to middle Havensville Shale). These units would form a moderate to poorly developed Kansas cyclothem. The lack of a well developed, offshore, non-arenaceous, conodont rich, black phosphatic shale, would

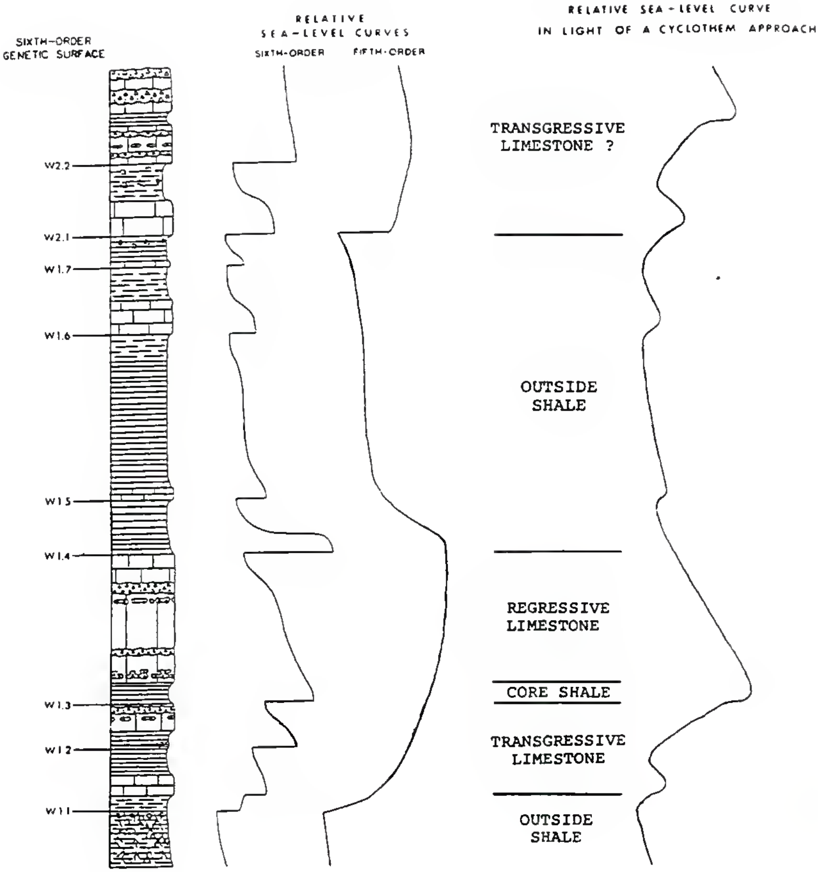

Figure 32. Comparison of relative sea-level curves using a cyclothem approach (i.e., Heckel, 1986) as opposed to hierarchal genetic stratigraphy.

classify this cyclothem ss an "intermediate cycle" (Heckel, 1986), with the smaller limestones, such as the molluscan limestone at the top of the Speiser Shale representing portions of "minor" cycles (Heckel, 1986). This "intermediate cycle" (cyclothem) is on the ssme scale (i.e., represents 300 to 500ka) as a fifth-order T-R unit (i.e., the Threemile fifth-order T-R unit).

In accordance with this cyclothem approach (Heckel, 1986), the transgressive apex would necessarily be plsced within the thin, offshore shale (i.e., calcareous shale just above genetic surface W1.3, Figure 32); just above the thin, transgressive limestone (i.e., lower Threemile cherty limestone just below genetic surface W1.3, Figure 32). Transgression would be considered gradual from the top of the Speiser Shale up to this transgressive apex (calcareous shale), followed by gradual regression upward into the Havensville Shale. In contrast, information presented in this investigation shows that the most open marine conditions (i.e., transgressive apex) for this stratigraphic interval (i.e., upper Speiser Shale to upper Havensville Shale) were preserved in the calcareous shale at the top of the Threemile Limestone (i.e., just above genetic surface W1.4, Figure 32). As such, the transgressive spex is located at the top of a regressive limestone of Heckel's (1977, 1986) spproach discussed above. In addition, data presented in this investigation shows that neither transgression, nor the

subsequent regression, at the fifth-order scale (i.e., cyclothems and fifth-order T-R units; Busch and Rollins, 1984), occurred gradually. Instead, sea-level changes at this fifth-order scale were the net result of a series of abrupt deepening events that punctuated longer intervals of ahallowing. That is, the fifth-order T-R units are a series of smale-scale (0.2 to 2.5m) shallowing upward units, aeparated by surfaces (i.e., genetic aurfaces) marking abrupt changes to deeper facies (i.e., PACs of Goodwin and Anderson, 1985).

In summary, use of a cyclothem approach (i.e., Heckel, 1986) in analysis of the Wreford Limestone Formation and the subjacent Speiser Shale would exclude important information pertaining to the sea-level changes that took place during the deposition of these sediments, and it would lead to the misplacement of the transgressive apex for the fifth-order T-R unit in the lower portion (i.e., upper Speiser Shale to upper Havensville Shale) of the study interval.

Wreford Sixth-Order Paleogeographic Changes

Paleogeographic maps were drawn for times of maximum transgression and maximum regression achieved in each sixth-order T-R unit within the Threemile fifth-order T-R unit. Each map is produced by listing, at the appropriate locality,

the lithologic and paleontologic characteristics of that unit representing either maximum transgression or maximum regression within each aixth-order T-R unit. Any general trenda or changes in the lithology or paleontology were then marked on the map. Isopach maps for total thickness of each sixth-order T-R unit were also made. Additional information, particularly for the isopach maps, was obtained from stratigraphic aections measured and described by Hattin (1957, plates 1 and 2) and was used to supplement data obtained in this investigation.

To locate recurrent facies changes, composite paleogeographic maps where also made for both maximum transgression and maximum regression. These maps were produced by overlaying all facies changes from each paleogeographic map to form a single transgressive and regreasive composite map. The possible influence of structural features is indicated in those areas over which recurrent facies changes occurred.

Information from both paleogeographic and isopach maps can be used to delineate topographic highs and lows within the basin of deposition. The maps also illustrate the development of the Threemile fifth-order T-R unit as a sequence of sixth-order T-R units.

Unit W1.1--Maximum transgression for sixth-order T-R unit W1.1 (Figure 33) generally is represented by a "molluscan" limestone containing common _Aviculopecten_,

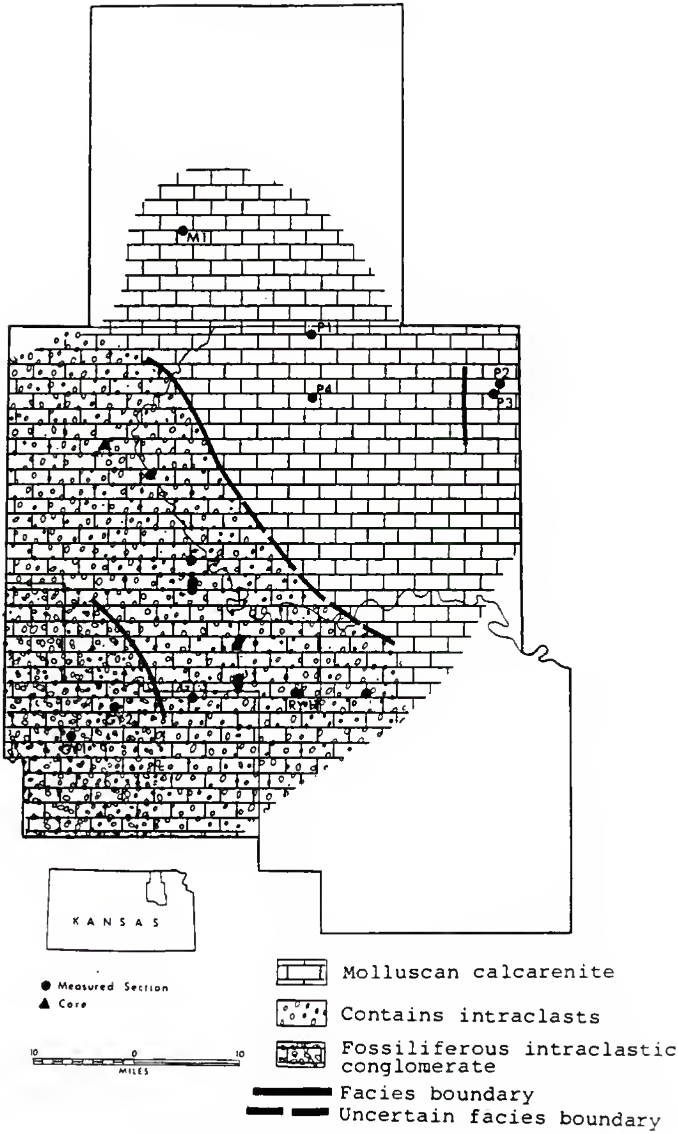

Figure 33. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.1.

Aviculopinna, small gastropods, ostracodes, occasional bryozoans, and occaaional limestone intraclaats. This limestone represents restricted subtidal environments. At localities GY1 and GY2 (aouthwest portion of the map) the limeatone forms an intraclastic conglomerate (calcirudite) indicating a higher energy environment for the southwest part of the area. Intraclasts decrease in abundance to the north and northeast and are absent in the northeast part of the map (localities M1, P1, P2, P3, and P4). This suggests that the source of the intraclasts is west-southwest of the study area. Grain size also decreaaes to the north and northeast. Overall abundance of fossils decreases northward, with the exception of localities P2 and P3, where diversity is slightly higher than at other localities. This suggests that relatively more open marine conditions existed to the east and in the south-central parts (localities P2, P3, GY3, and RY11) of the area during maximum trangression of T-R unit W1.1.

Maximum regression in T-R unit W1.1 is represented by a sparsely fossiliferous, calcareous shale dominated by Orbiculoidea and Aviculopecten with occasional productid brachiopod fragments, Straparollus, Permophorus, and rare amall crinoid and bryozoa fragments (Figure 34). These foasils tend to be mostly whole in the southern portion of the study area (south of locality RY3) and mostly fragmented in the northern portion (north of locality RY3) of the study

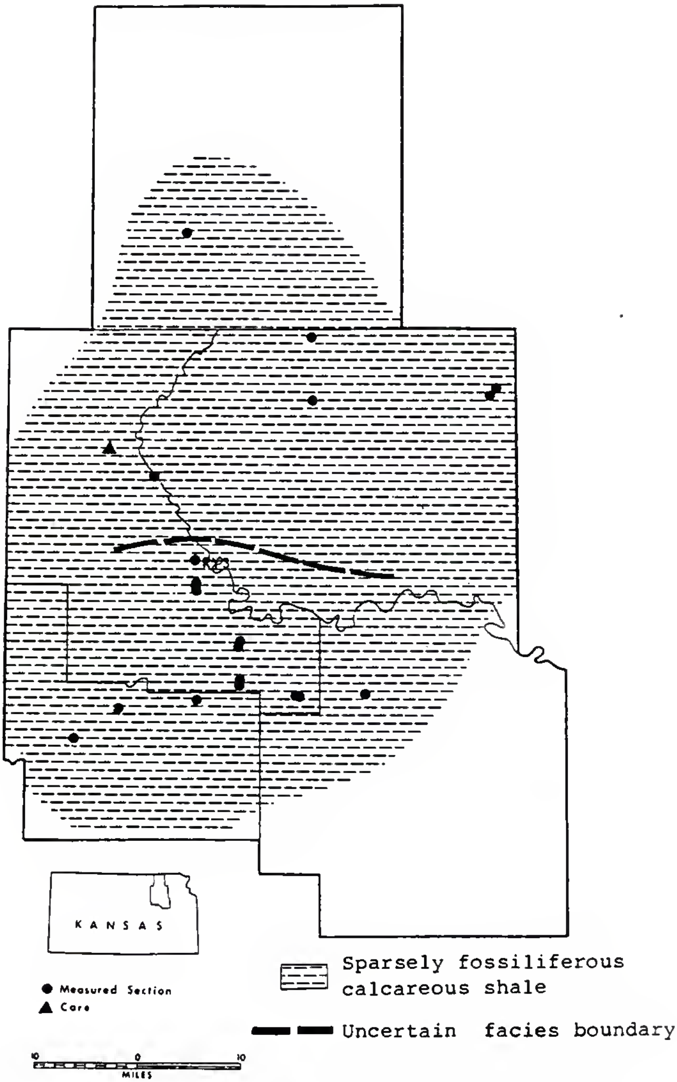

Figure 34. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.1.

area. This facies is thought to represent a relatively restricted, ahallow marine environment (i.e., intertidal mudflat).

Sixth-order T-R unit W1.1 is thickest in the southeast and south-central portions of the area and thins toward the north, northeast, and west (Figure 35). The overall decrease in fossils, loss of intraclasts, decrease in grain size during maximum transgression (Figure 33), and the increase in fragmented fossils during maximum regression (Figure 34), correspond to the thinning of sixth-order T-R unit W1.1 to the north and northeast. Higher fossil content and percent of intraclasts (during maximum transgression), and fewer fragmented shells (during maximum regression), correspond with the thicker parts of T-R unit W1.1 in the south. These facies and isopachous changes indicate that the southern portion of the study area was probably topographically lower than the northern portion during deposition of sixth-order T-R unit W1.1.

Unit W1.2--Maximum transgression for sixth-order T-R unit W1.2 is represented by a very fossiliferous, calcareous shale (Figure 36) with common to abundant crinoids, *Derbyia*, *Composita*, bryozoans, *Neochonetes*, echinoderms and productids (*Reticulatia*, *Linoproductus*). This calcareous shale represents an open, normal marine, subtidal depositional environment. No significant changes or trends for this maximum transgressive phase are seen within the study area,

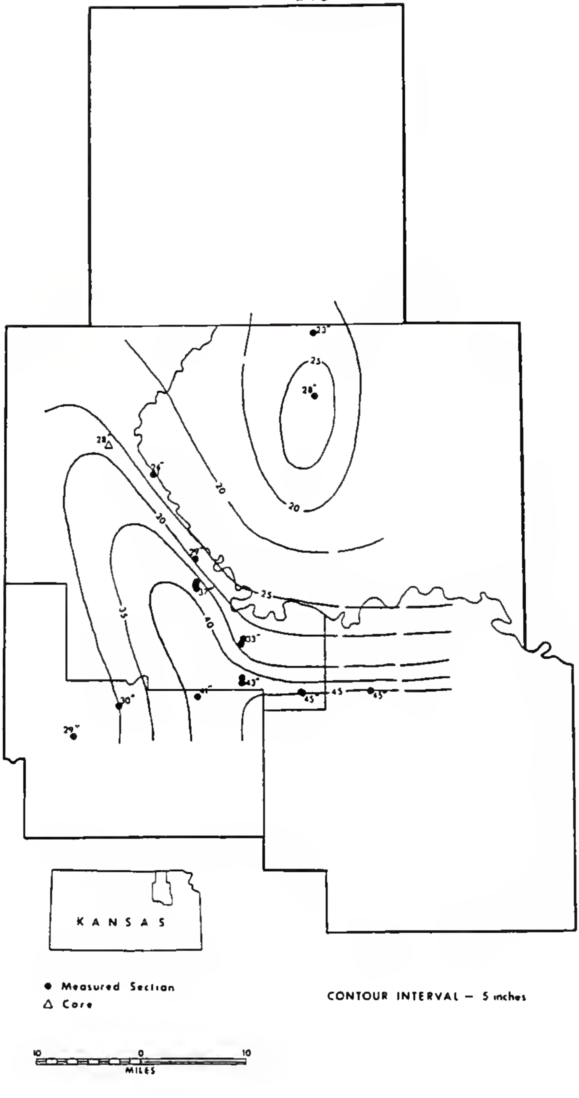

Figure 35. Isopach map for sixth-order T-R unit W1.1.

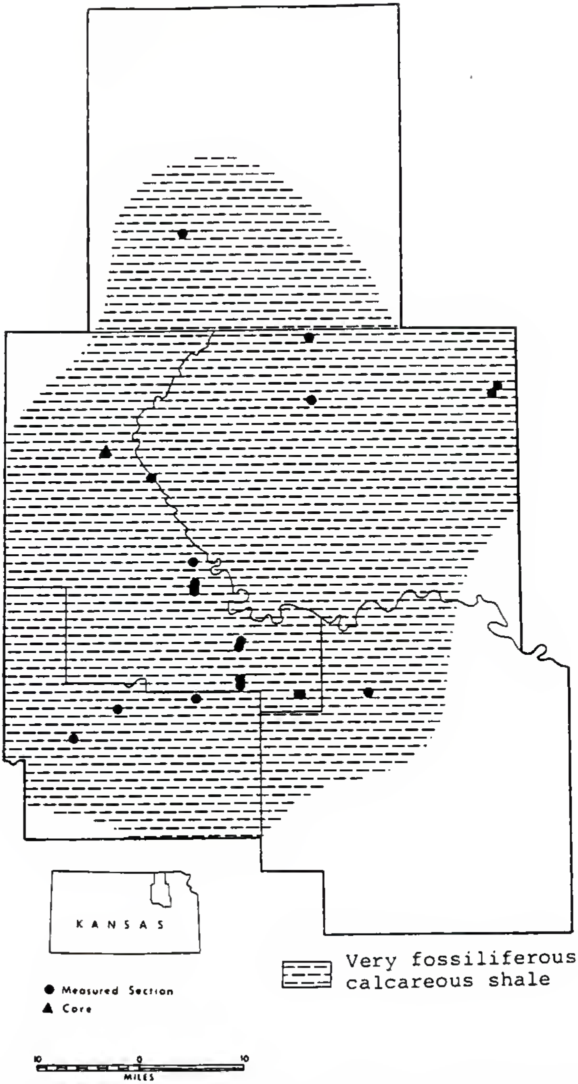

Figure 36. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.2.

therefore this facies is a good marker bed in this area.

The facies representing maximum regression in T-R unit W1.2 (Figure 37) is an argillaceous, fossiliferous, fine calcarenite containing fragments of brachiopod shells, bryozoans, crinoids, echinoids, productid apines and ostracodes and sparse to rare intraclasts and algal fragments. Relative fossil abundance within this fine calcarenite decreases slightly northward. This fine calcarenite is interpreted to have been deposited in a relatively restricted, intertidal environment. The intraclasts are limited in geographic extent to the aouthwestern portion (localilties RY3, RY6, GY2, and GY3) of the study area (Figure 37).

Figure 38 is a paleogeographic map showing the geographic extent of the Wellerella facies in the fossiliferous fine calcarenite at the top of sixth-order T-R unit W1.2. Abundant articulated Wellerella are found in the southeastern part of the area, indicating that relatively more open marine conditions (possibly due to a paleotopographic low) existed in this area. In addition to the sections measured in this investigation, information obtained from Hattin (1957) was used to more accurately delineate the geographic extent of this Wellerella facies (Figure 38).

Overall thickness of sixth-order T-R unit W1.2 decreases to the north and northwest (Figure 39). In general the

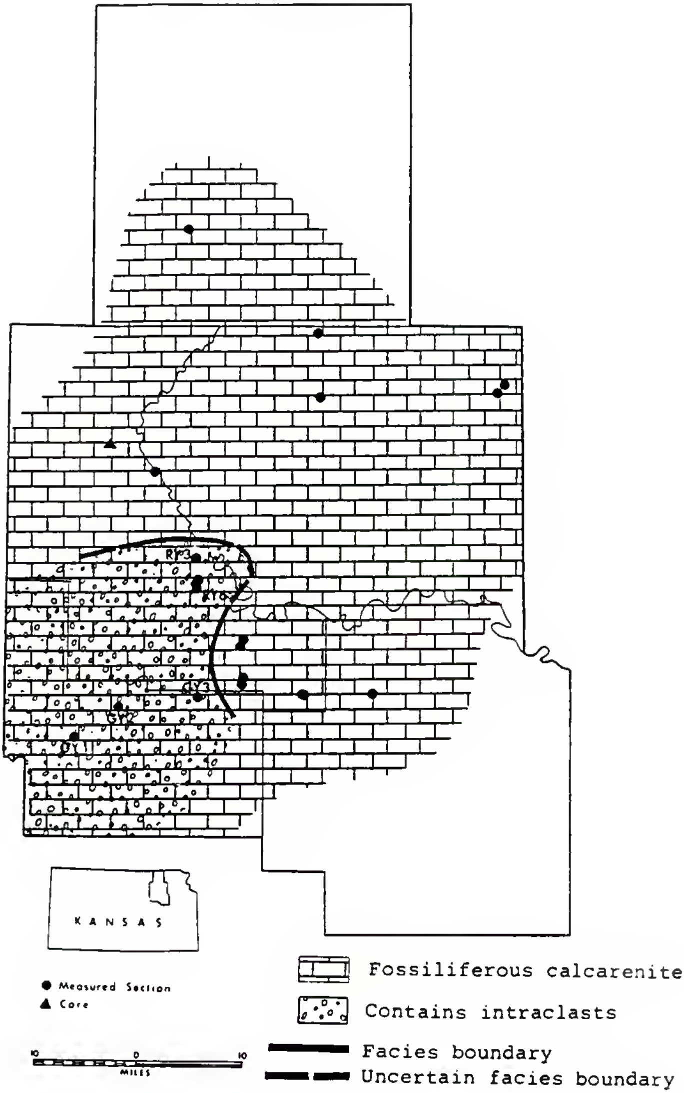

Figure 37. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.2.

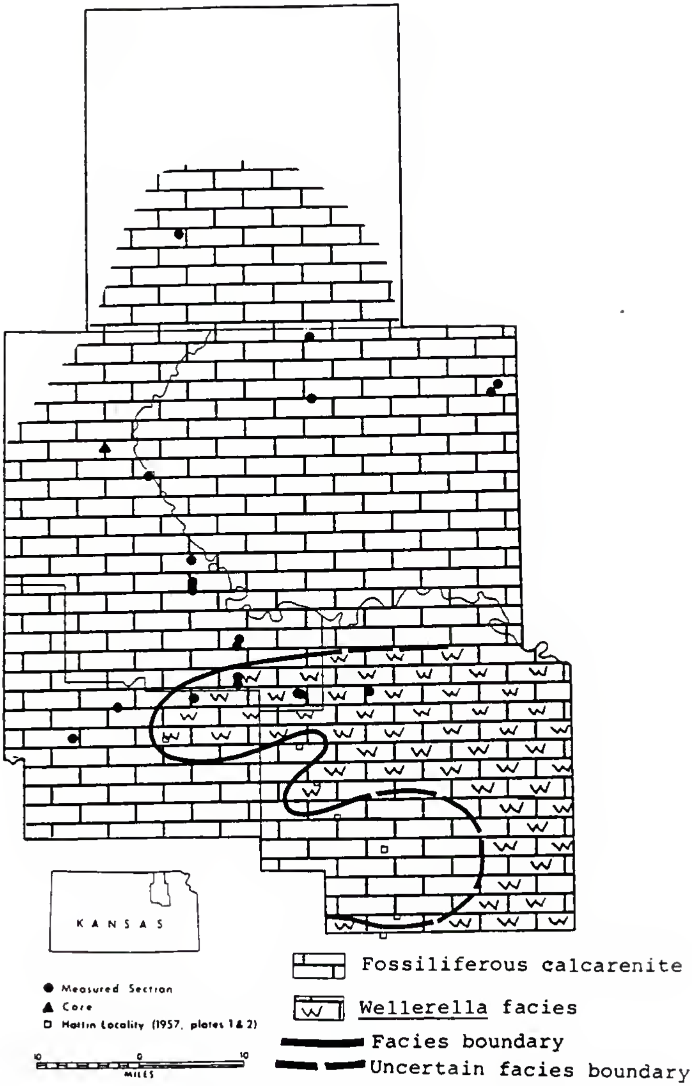

Figure 38. Paleogeographic map showing extent of <u>Wellerella</u> facies in the limestone at the top of aixth-order T-R unit W1.2.

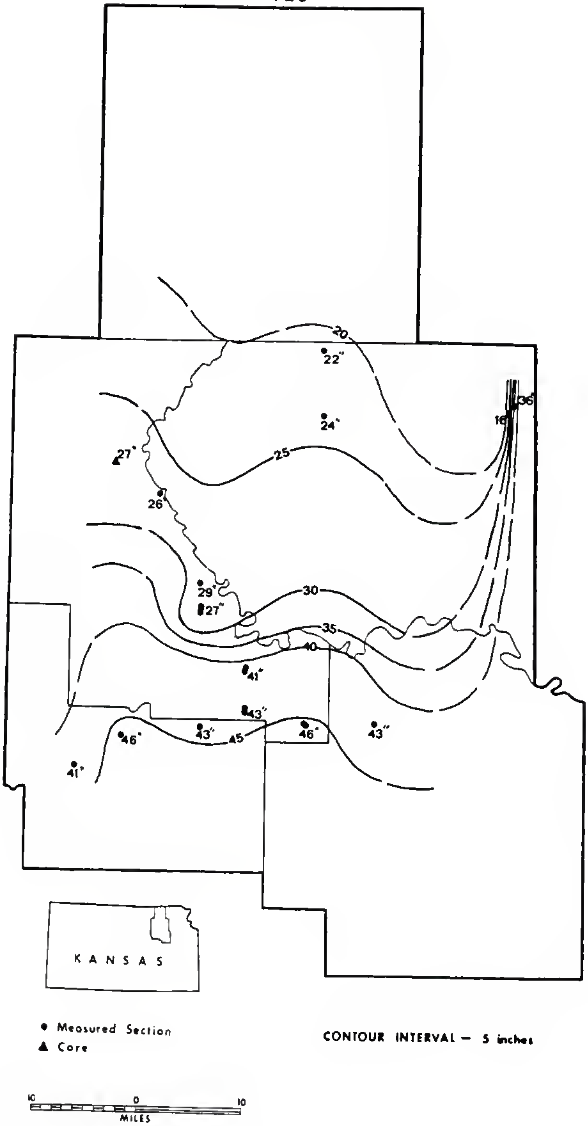

Figure 39. Isopach map for sixth-order T-R unit W1.2.

overall decrease in fossil abundance and diveraity corresponds to the overall thinning of the aixth-order T-R unit (W1.2) in the northern part of the area. The _Wellerella_ faciea in the southeast coincides with the thicker part of sixth-order T-R unit W1.2.

Unit W1.3--Maximum transgression for sixth-order T-R unit W1.3 (Figure 40) is represented by highly fossiliferous, calcareous shale and very argillaceous limestone. Both contain a diverae fossil assemblage including _Composita_, _Derbyia_, crinoids, bryozoans, _Neochonetes_, _Reticulatia_, _Linoproductus_, echinoids, and ostracodes. Sparse to rare specimens of _Enteletes_, _Wellerella_, _Straparollus_, and trilobites also occur at most localities. This highly fossiliferous facies represents deposition in an open marine, aubtidal environment. In the central and western part of the area the facies that developed for this time is considered a calcareous shale; however, to the east it becomes more calcareous and is considered a very argillaceous limeatone (Figure 40).

Maximum regression for sixth-order T-R unit W1.3 (Figure 41) ia represented by a chert-bearing, slightly argillaceous, fossiliferous, fine calcarenite containing abraded fragments of bryozoans, brachiopods, crinoids, echinoida, productid spines, and ostracodes. Thin section analysis of samples from localities GY3 and RY6 indicate that the fossil fragments are angular to aubrounded, with

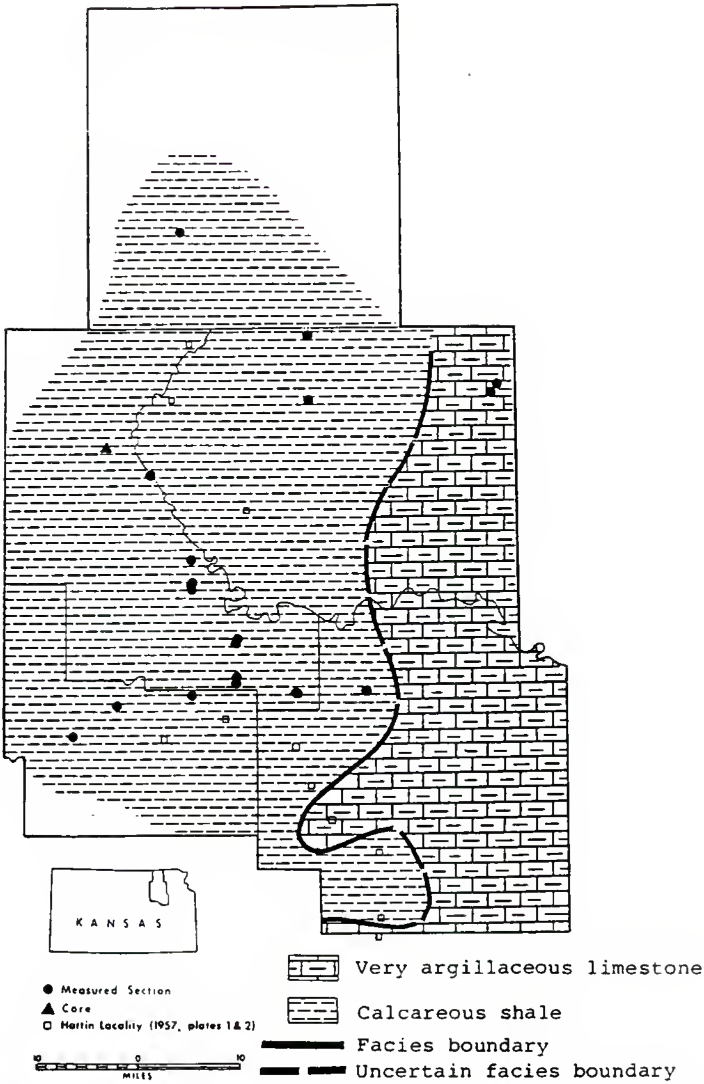

Figure 40. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.3.

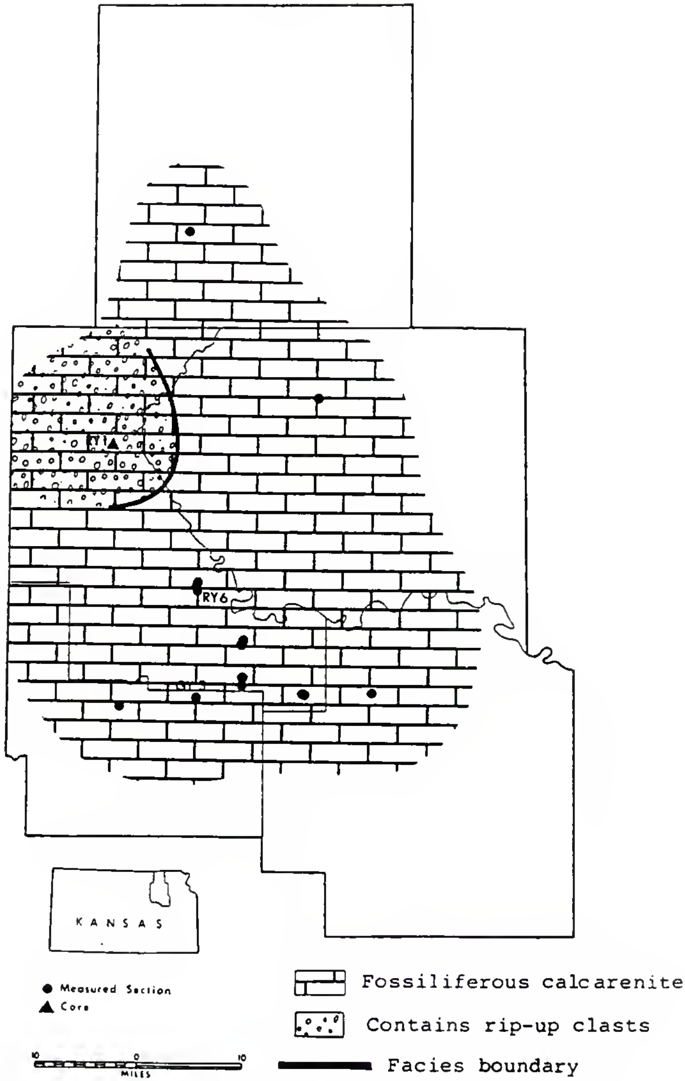

Figure 41. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.3.

occasional well rounded bryozoan and brachiopod ahell fragments. This limestone is interpreted to have been deposited in a relatively restricted, intertidal (and possibly very shallow subtidal) environment. In the northwestern part of the area (locality RY1) the limestone contains large sub-rounded, fossiliferous (brachiopods, bryozoans, crinoids, and echinoids) limestone rip-up clasts. These rip-up clasts, having the same composition as that characterizing this same facies to the south and east, and may have come from areas immediately to the east and south of locality RY1. It is also possible that they were formed locally, as a result of a high energy (i.e., coastal storm) phenomena. The limestone also becomes very argillaceous at this locality (RY1), containing thin layers of very argillaceous debris, indicating a more restricted (upper intertidal to aupratidal) environment of deposition for the northwestern part of the area.

The isopach map for sixth-order T-R unit W1.3 (Figure 42) ahows an overall thinning northward in the area of investigation. The more restricted environments found in the northwest part of the study area coincide with the relative thinning of sediments in the north. These concomitant trends suggest the presence of a topographic high in the northwest part of the area during deposition of sixth-order T-R unit W1.3.

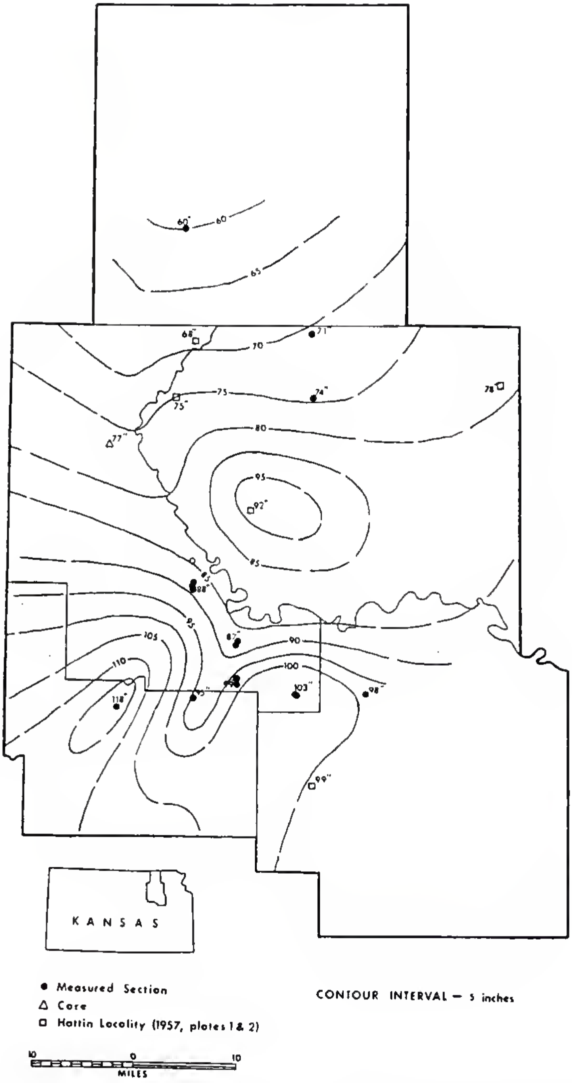

Figure 42. Isopach map for sixth-order T-R unit W1.3.

Unit W1.4--Maximum transgression for sixth-order T-R unit W1.4 is represented by a highly fossiliferous, calcareous shale (Figure 43). The dominant fossils include *Derbyia*, *Composita*, crinoids, bryozoans, chonetids, *Reticulatia*, *Linoproductus*, echinoids, and ostracodes. Sparse to rare specimens of *Enteletes*, *Straparollus*, *Meekella*, and trilobites were also found at most localities. The depositional environment for this fossiliferous shale is interpreted as open (subtidal) marine. Figure 43 shows that no notable lithologic or faunal changes occur within the study area.

A very sparsely fossiliferous shale represents maximum regression in sixth-order T-R unit W1.4 (Figure 44). This shale is olive green and dark gray (mottled) in color and contains sparse to rare *Aviculopecten*, *Permophorus*, and bivalve shell fragments. Rare small crinoid columnals were found at localities RY1, RY9, and RY11. This shale represents deposition in a shallow, restricted, intertidal or shallow subtidal (e.g., intertidal mudflat or lagoon) environment. An olive green silty mudstone containing rare *Aviculopecten*, bellerophontaceans (one specimen), and orthoconic cephalopods (one specimen) was found at locality GY3 in the southern portion of the study area (Figure 44).

Sixth-order T-R unit W1.4 is thickest in the north-central and south-central part of the study area (Figure 45). Thinning occurs in the northwest and southeast corners of

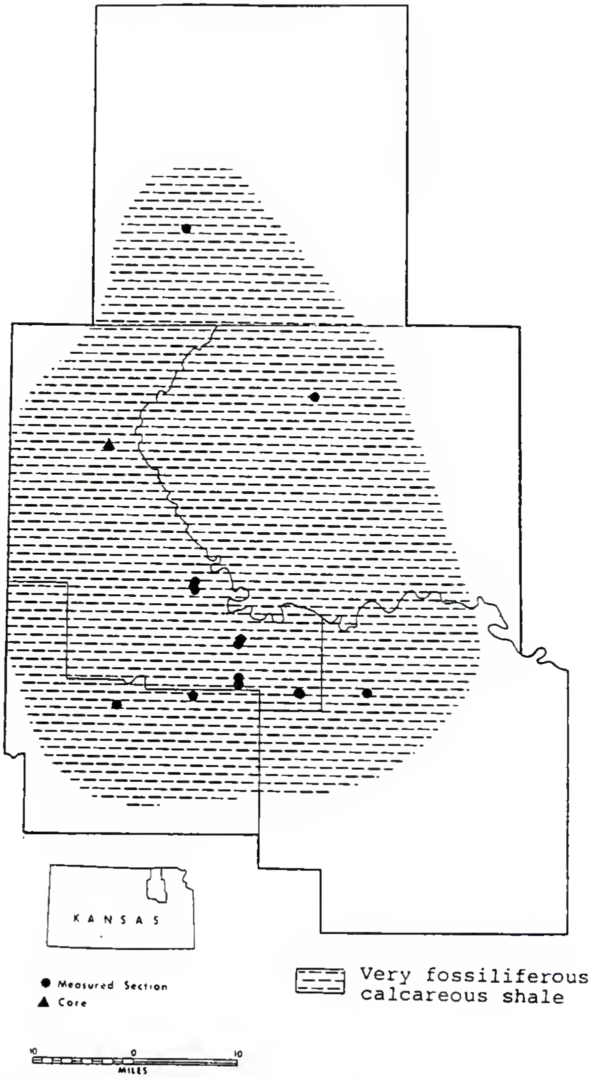

Figure 43. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.4.

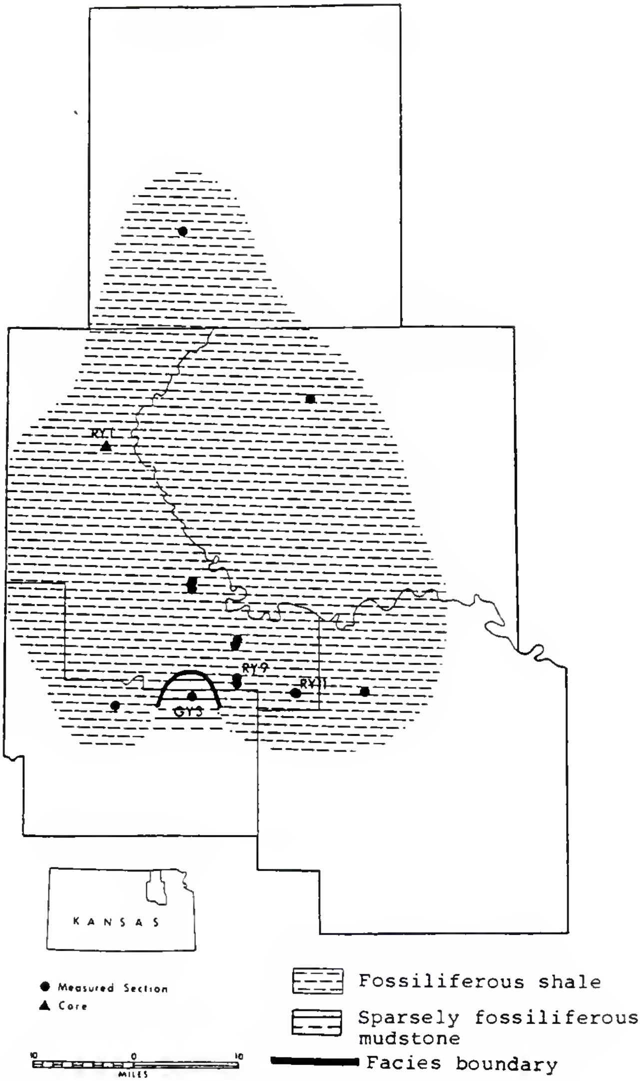

Figure 44. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.4.

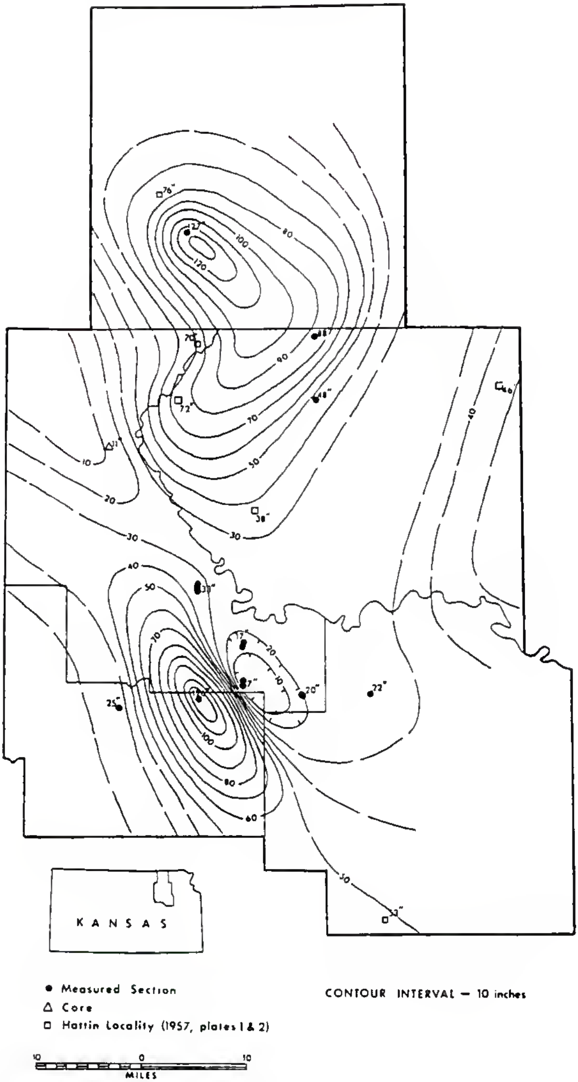

Figure 45. Isopach map for sixth-order T-R unit W1.4.

Riley County, the northeastern and south-central part of Pottawatomie County, and in the northwest part of Wabaunsee County. The thick and thin parts of sixth-order T-R unit W1.4 show two distinct orientations; northwest to southeast and northeast to southwest. The change in lithology at locality GY3 (in the southern part of the area) coincides with a dramatic thickening of sixth-order T-R unit W1.4.

Unit W1.5--Maximum transgression, over most of the area, in sixth-order T-R unit W1.5 is represented by an argillaceous, fossiliferous calcirudite (Figure 46). This limestone is characterized by extremely abundant Aviculopecten, and common small gastropods. Sparse to rare bellerophonts, productid spines, and bryozoan fragments are also found at most localities. Paleoenvironmentally, this calcirudite represents deposition in a relatively restricted, shallow subtidal (possibly lower intertidal) environment. To the north of the study area (locality M1), the relative abundance of fossils in the calcirudite decreases. An argillaceous, sparsely fossiliferous (productid spines, and bivalve shell fragments) calcilutite was found at locality GY3 in northeastern Geary County (Figure 46). This sparsely fossiliferous calcilutite represents a more restricted (e.g., upper intertidal) environment than the surrounding Aviculopecten, (small) gastropod calcirudite.

At locality RY11 (southeast Riley County, Figure 46) maximum transgression is represented by a thick

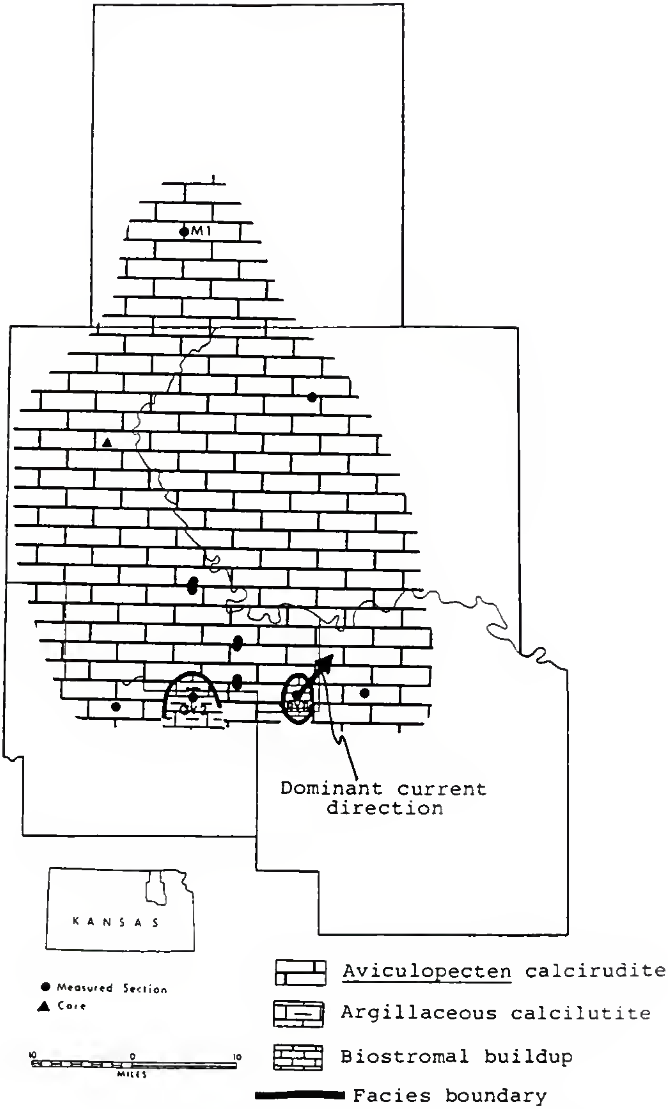

Figure 46. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.5.

(up to 3.16 m) biostromal buildup of fossil fragments and calcareous algae. Based on thin-section analysis, this limestone is a medium calcirudite composed of 32% filamentous algae (Girvanella?), 32% recrystallized calcite (microspar and sparry calcite), 4% micrite, and 32% other allochems (including bryozoans, pelecypods, gastropods, echinoids, crinoids, ostracodes, forams, intraclasts, and pellets). The limestone contains thin (1 to 4 mm) alternating layers of algal-rich and bioclast-rich zones in its lower portion, with overall grain size (bioclastic content) increasing upward through the unit. Sparse tubular, elongate, sponges(?) are found in the upper part of the limestone. Large-scale cross-beds are apparent in outcrop and paleocurrent direction from these cross-beds indicate a dominant east-northeast direction of transportation. This thick medium calcirudite indicates that shoaling (higher energy) conditions existed in the southeast corner (around locality RY11) of Riley County during maximum transgression of sixth-order T-R unit W1.5.

Maximum regression for sixth-order T-R unit W1.5 is represented by a number of different facies (Figure 47). The southwest part of the study area (localities GY2, GY3, and RY9) consists of a non-fossiliferous, green-gray, silty claystone containing sparse calcareous (caliche) nodules. No identifiable root traces were found. At localities GY2, and GY3 this silty claystone contains sparse to rare limestone

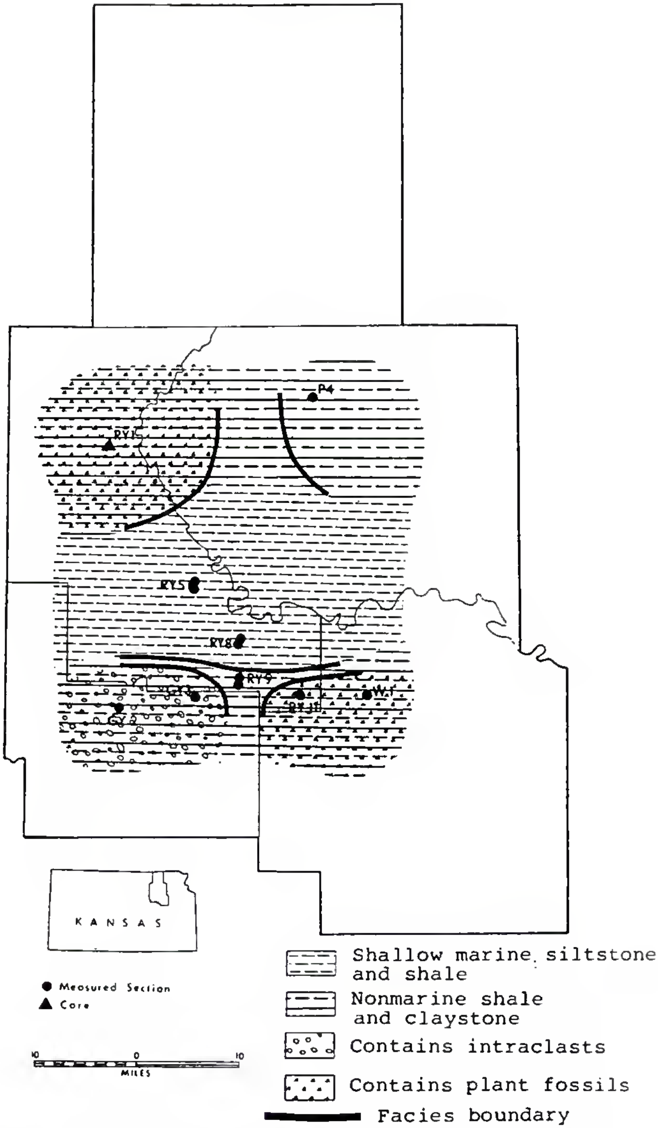

Figure 47. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.5.

intraclasts. The depositional environment for this silty claystone is interpreted as supratidal to alluvial (possibly representing a paleosol). In the southeast part of the study area (localities RY11 and W1) an olive green to green-gray shale to silty claystone occurs, containing sparse calcareous (caliche) nodules. Abundant plant fragments were found at locality RY11. The silty claystone at locality W1 contains sparse plant fragments with common carbonaceous films and macerals. This silty claystone-shale facies represents deposition in an alluvial (possibly low-lying coastal plain) environment.

The central part of the study area (localities RY5, and RY8) in sixth-order T-R unit W1.5 (Figure 47) is characterized by a sparsely fossiliferous (Permophorus) siltstone (locality RY5) or shale (locality RY8). Common horizontal burrows (Chondrites) were also found at locality RY5. This sparsely fossiliferous siltstone-shale facies in the central part of the study area represents deposition in a shallow, restricted, intertidal (e.g., intertidal mudflat or lagoon) environment receiving input of terrigenous mud from east and west.

Facies representing supratidal or alluvial (possibly low lying coastal plain) environments appear again in the northern part of the study area (Figure 47). A dark gray, non-fossiliferous shale containing sparse carbonaceous macerals and horizontal burrows (Chondrites) occurs in the

core at locality RY1 (Figure 47). Thin lenses of selenite and rock-gypsum also occur in this shale. The presence of evaporites at locality RY1 indicates that hypersaline conditions may have existed in northern Riley County during maximum regression of sixth-order T-R unit W1.5. Locality P4 in northern Pottawatomie County is represented by a non-fossiliferous, green-gray, sandy claystone and indicates deposition in an alluvial environment.

These regressive facies relationships in sixth-order T-R unit W1.5 indicate that a topographic low is present in the central part of the mapped area and that topographic highs occur in the southern (trending east-west in southern Riley, northern Geary, and northwestern Wabaunsee Counties) and northern part (northeastern Riley and northern Pottawatomie Counties) of the area (Figure 47).

The isopach map (Figure 48) for sixth-order T-R unit W1.5 shows that the overall thickness of the T-R unit decreases to the north. Nevertheless, a number of thickening and thinning trends, with northwest-southeast and northeast-southwest orientations, are seen throughout the study area. Comparison of the isopach map with the paleogeographic maps (Figures 46 and 47) shows a correlation between the thins and those areas representing paleoenvironmentally more restricted environments (i.e., during maximum transgression) or subaerial deposition (i.e., during maximum regression).

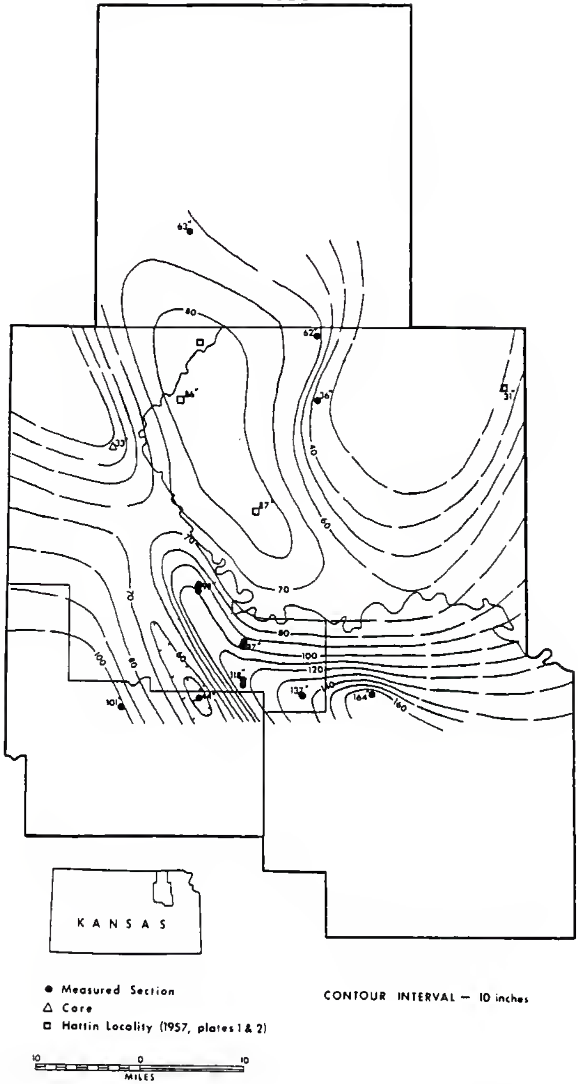

Figure 48. Isopach map for sixth-order T-R unit W1.5.

Unit W1.6--Most of the study area during maximum transgression in sixth-order T-R unit W1.6 was covered by an argillaceous, fossiliferous calcilutite (Figure 49). Fossils of this facies include bivalves (*Aviculopecten* and *Permophorus*), ostracodes, and productid spines. Small gastropods are found at localities GY3 and P4 (Figure 49). Sparse plant fragments were found at locality W1. In the southwest (localities GY2, GY3, and RY4) and southeast (locality W1) parts of the study area (Figure 49), the limestone contains shale and limestone intraclasts, some of which are algal (*Osagia*) coated. Grain-size of the limestone increases in those areas containing intraclasts. At localities RY4 and W1, the limestone is considered a calcirudite because of sparse to common large (up to 1.3 cm) intraclasts. This limestone is interpreted to have been deposited in a shallow subtidal to lower intertidal environment that becomes relatively more restricted in areas containing limestone and shale intraclasts. At locality RY11, in southeastern Riley County, maximum transgression is represented by a dark to medium gray shale containing abundant plant fragments and macerals forming a coal smut. This shale (with coal smut) represents deposition in a relatively humid, swamp like, nonmarine environment. This nonmarine environment indicates the presence of a topographic high in southeastern Riley County.

Maximum regression in sixth-order T-R unit W1.6 is

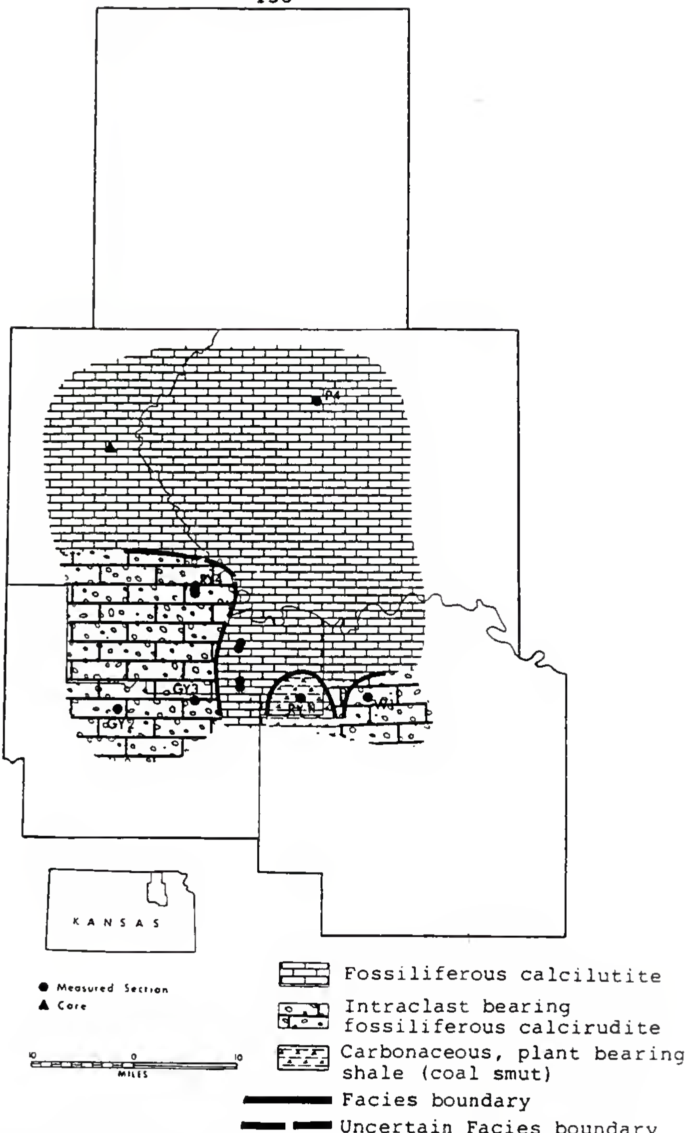

Figure 49. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.6.

represented by a number of facies (Figure 50). In the southwest part of the area (localities GY2, GY3, RY8, and RY4) maximum regression is represented by green-gray and dark gray (mottled), sparsely fossiliferous (*Permophorus*, *Aviculopecten*, and ostracodes) shale with thin limestone lenses (Figure 50). This shale represents deposition in a restricted, shallow, intertidal (e.g., intertidal mudflat or lagoon) environment. A non-fossiliferous shale containing occasional limestone lenses occurs at localities RY1 and RY9. The depositional environment for this shale is interpreted as supratidal. The southeastern part of the study area (localities RY11 and W1) is characterized by a green-gray claystone containing sparse plant fragments and caliche nodules. This claystone represents deposition in a subaerial (e.g., paleosol) environment. In northern Pottawatomie County, at locality P4, maximum regression is represented by a non-fossiliferous, sandy claystone that is interpreted to have been deposited in a subaerial (supratidal to low lying coastal plain) environment.

Sixth-order T-R unit W1.6 is thinnest in the southern and western parts of the area and thickens to the northeast (Figure 51). The relatively humid, coal forming, non-marine environment found at locality RY11 coincides with the thinnest part of sixth-order T-R unit W1.6 in southeastern Riley County.

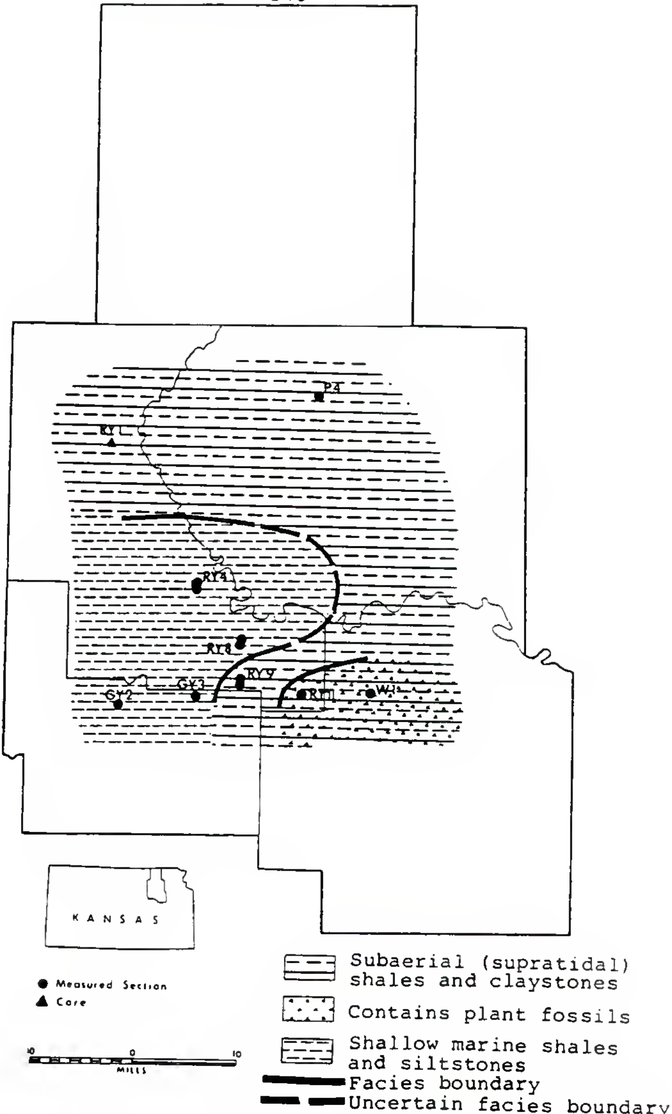

Figure 50. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.6.

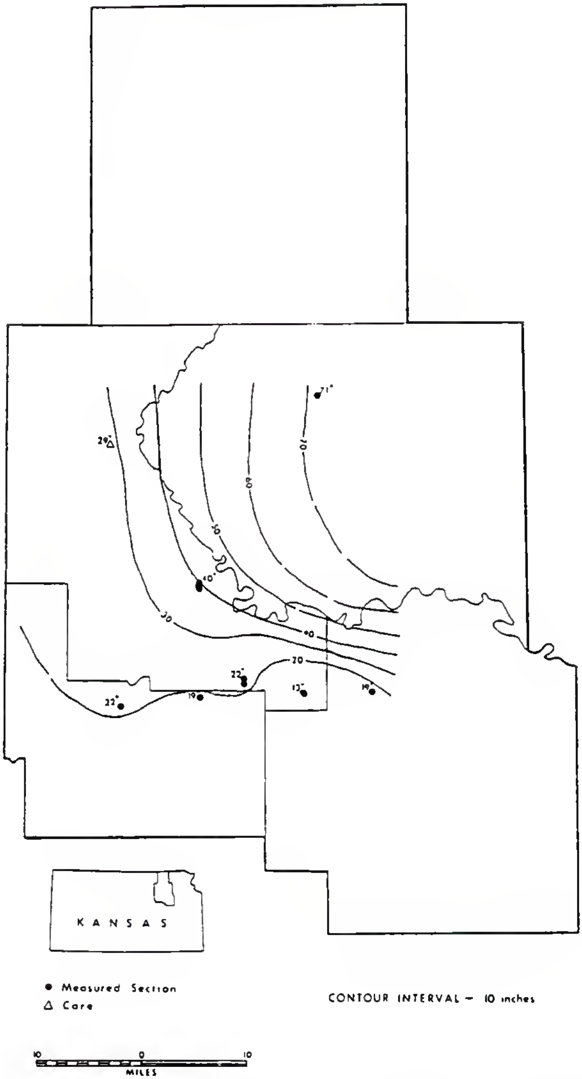

Figure 51. Isopach map for sixth-order T-R unit W1.6.

Unit W1.7--Maximum transgression in sixth-order T-R unit W1.7, over most of the study area, is represented by a sparsely fossiliferous calcilutite containing bivalve shell fragments, ostracodes, and (at localities P4, and W1) small gastropods (Figure 52). The depositional environment for this calcilutite is interpreted as shallow (restricted) intertidal. In the southwest part of the study area (localities GY2 and GY3) maximum transgression is represented by a fossiliferous, coarse calcarenite containing large (up to 3.2 cm) limestone intraclasts and Osagia-coated grains. Fossils include bivalve and brachiopod shell fragments, ostracodes, (rare) small crinoids, and (at locality GY3) small gastropods. This coarse calcarenite is interpreted to have been deposited in a relatively restricted, shallow intertidal environment. The southeast corner of Riley County (locality RY11, Figure 52) is characterized by sparsely fossiliferous claystone containing Aviculopecten, Permophorus, and ostracodes with sparse plant fragments. This claystone is interpreted to have been deposited in a restricted, shallow (upper) intertidal environment.

A majority of the study area during maximum regression in sixth-order T-R unit W1.7 is characterized by a non-fossiliferous, green-gray claystone containing sparse to common calcareous nodules (Figure 53). In the southeastern part of the area (localities RY11 and W1) plant fossils are common in this claystone. In the core at locality RY1 this

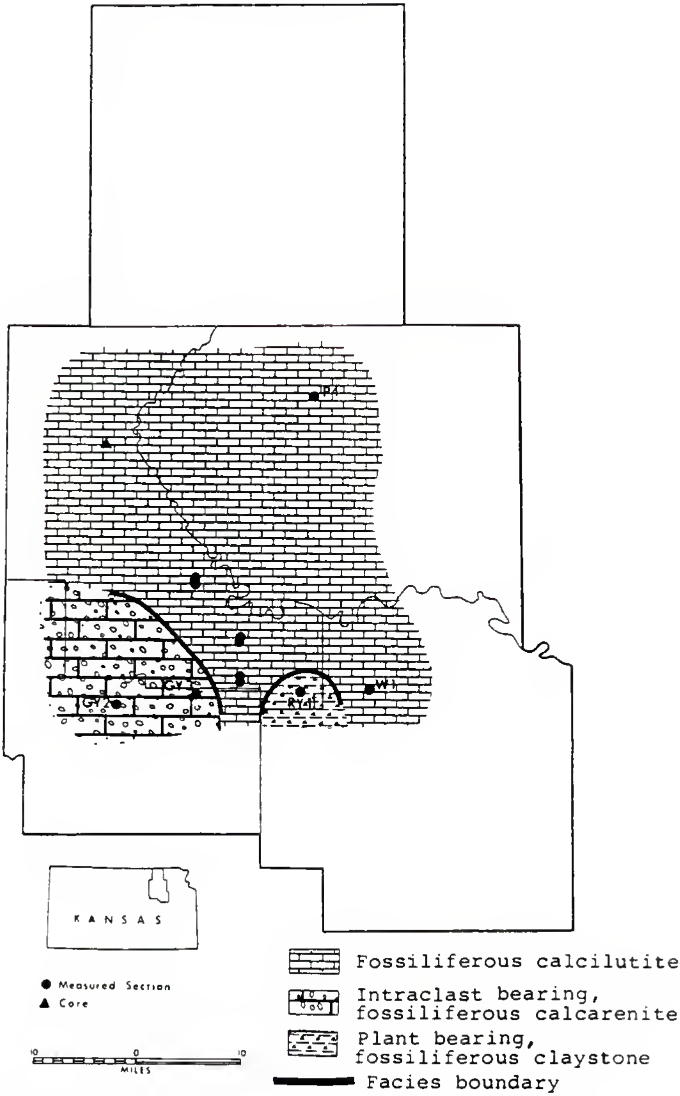

Figure 52. Paleogeographic map showing the facies at maximum transgression in sixth-order T-R unit W1.7.

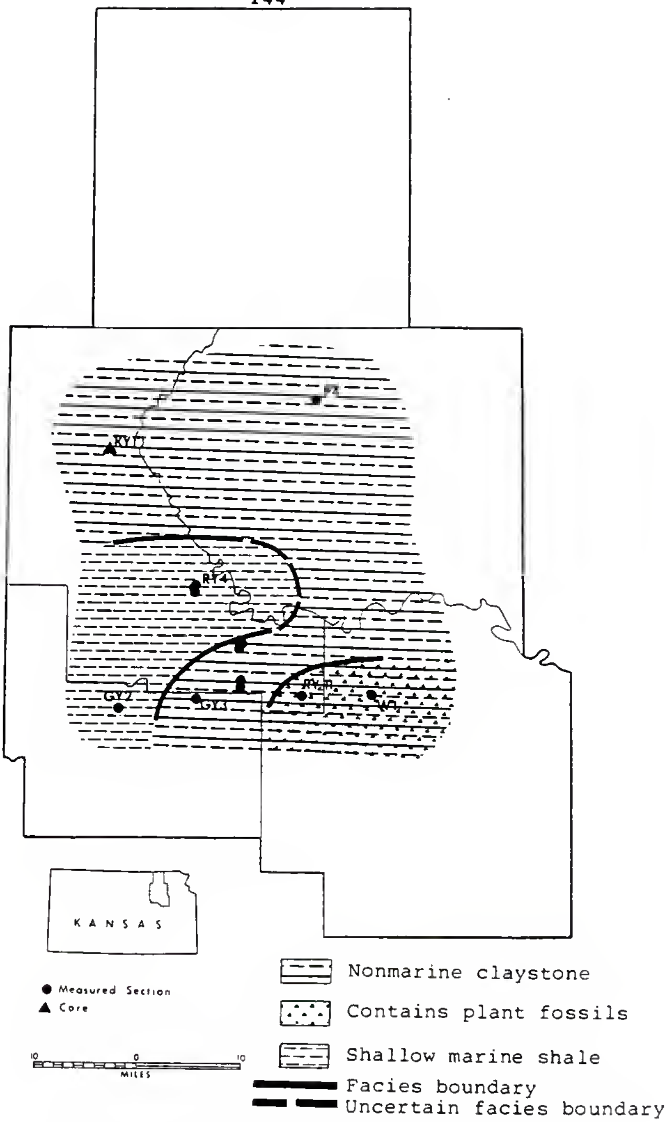

Figure 53. Paleogeographic map showing the facies at maximum regression in sixth-order T-R unit W1.7.

claystone contains sparse globular masses of white gypsum. The presence of collapse structures (localities P4 and GY3) in this claystone indicate that evaporites may also have been present at these localities. Presence of evaporites in this claystone (at localities RY, P4, and GY3) would indicate that sabkha-like conditions existed in the northern and south-central parts of the area. In the southeastern part of the area (localities RY11 and W1) plant fossils are common in this claystone. In the southeastern part of the area then, this claystone represents a relatively more humid supratidal to alluvial (i.e., low lying coastal plain) environment.

In the southwest part of the area (localities GY2, RY4) maximum regression is represented by a sparsely fossiliferous shale containing bivalve shell fragments (Lingula at locality RY4) and ostracodes. The facies distributions seen on the paleogeographic map representing maximum regression for sixth-order T-R unit W1.7 (Figure 53) indicate that the southwestern part of the area (localities GY2, and RY4) was topographically lower that the remainder of the study area.

The isopach map for sixth-order T-R unit W1.7 (Figure 54) shows a thickening to the northwest, with the thinnest portion of the sixth-order T-R unit in the central (locality RY4) and southeastern parts of the area.

Composite Facies Maps.--The composite maps of facies changes at maximum transgression (Figure 55) and maximum regression (Figure 56) for sixth-order T-R units W1.1 through

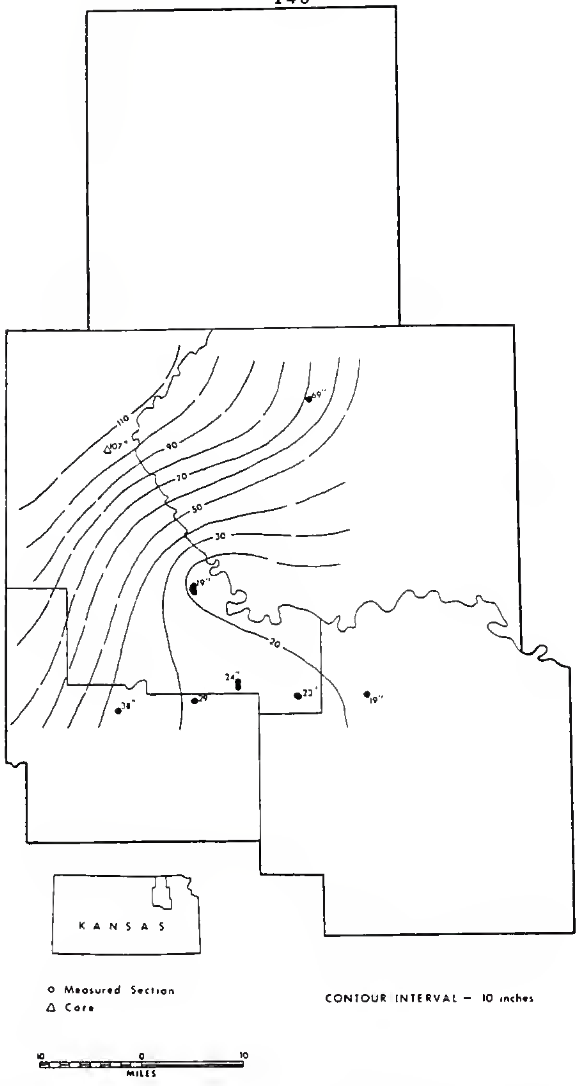

Figure 54. Isopach map for sixth-order T-R unit W1.7.

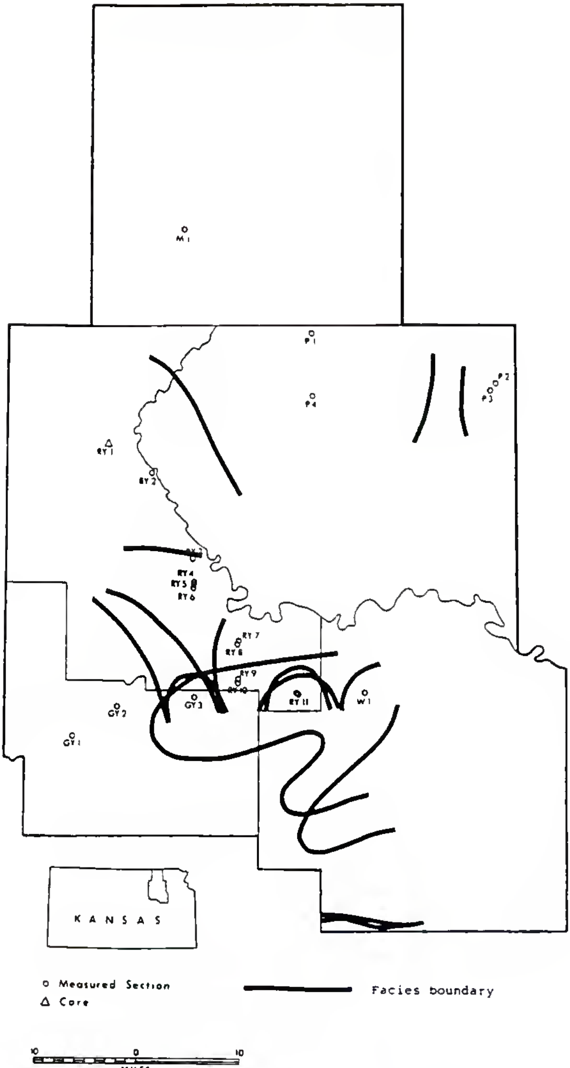

Figure 55. Composite map of facies changes at maximum transgression for sixth-order T-R units W1.1-W1.7.

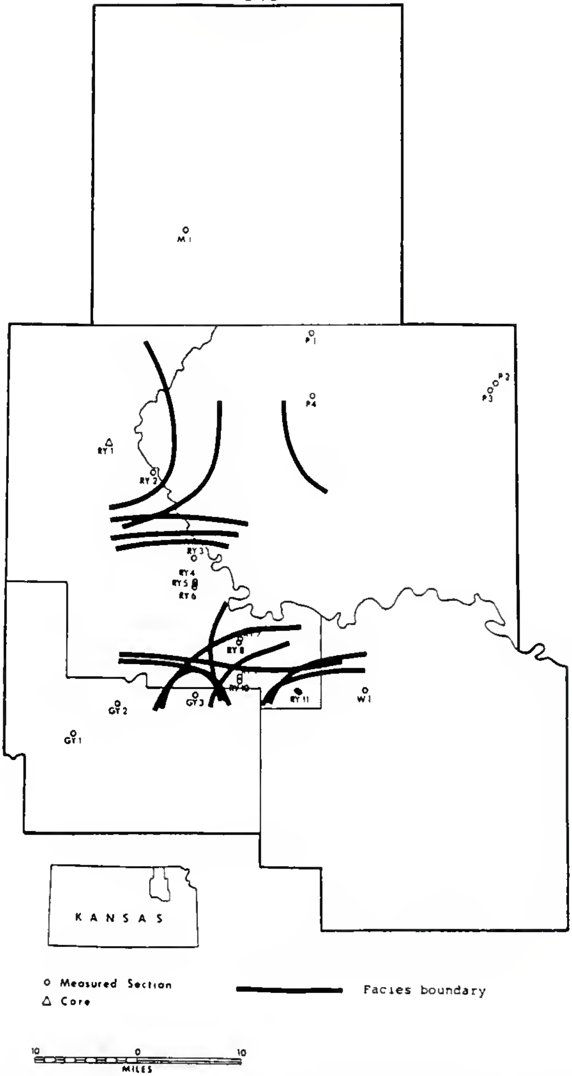

Figure 56. Composite map of facies changes at maximum regression for sixth-order T-R units W1.1-W1.7.

W1.7 show that the majority of facies changes take place along an east-west trending band (line) in southern Riley, northern Geary, and northwestern Wabaunsee counties. Other areas which contain recurrent facies changes (at least two separate closely-spaced facies changes) are found in northeastern Pottawatomie, and western and southwestern Wabaunsee counties (during maximum transgression, Figure 55). During maximum regression (Figure 56) recurrent facies are also found in east-central Riley, and western Pottawatomie counties. These recurrent facies changes, illustrated in Figures 55 and 56, suggest the possible influence of structural features (discussed below) on the deposition of Wreford sediments.

Summary of Paleogeographic Trends.--The paleogeographic maps, for both maximum transgression and regression in each sixth-order T-R unit, illustrate the gradual (shallowing upward) paleoenvironmental changes that occurred between genetic surfaces and the episodic (i.e., environmentally disjunct) changes that occurred at genetic surfaces. These maps also illustrate the development of the Threemile fifth-order T-R unit as a sequence of sixth-order T-R units. The maps showing maximum transgression for sixth-order T-R units W1.1-W1.4 (Figures 33, 36, 40, and 43) illustrate a series of successively greater transgressions forming the Threemile fifth-order transgressive sequence. The map showing maximum transgression for sixth-order T-R unit W1.4

illustrates the time of most transgressive conditions for not only that sixth-order T-R unit, but also for the Threemile fifth-order T-R unit. Overall trends in the fifth-order transgressive sequence include an overall shallowing of facies towards the northern part of the study area, and an overall thickening of sixth-order T-R units in the southern and southeastern parts of the area.

Maps showing maximum transgression for sixth-order T-R units W1.5-W1.7 (Figures 46, 49, and 52) illustrate a series of successively less extensive transgressions that form the Threemile fifth-order regressive sequence. Overall trends include an overall shallowing of facies to the north and in parts of southern and southeastern Riley County and northern Geary County. Only at the top of the regressive sequence (sixth-order T-R units W1.6 and W1.7) do sixth-order T-R units show an overall thickening to the north and northwest.

The overall facies changes in the fifth-order transgressive sequence (sixth-order T-R units W1.1-W1.4) indicate that the northern and southwestern portions of the study area were topographically higher than the southern and central parts. In the fifth-order regressive sequence (sixth-order T-R units W1.5-W1.7) sedimentation was effected by a topographic high trending east-west along southern Riley, northern Geary, and northwestern Wabaunsee counties. The composite paleogeographic maps (Figures 55 and 56) clearly show the numerous facies changes which occur in

this part of the area. The effect of this topographic high is more pronounced in the maximum regressive phases (Figures 44, 47, 50, and 53) of the sixth-order T-R unita, as illustrated in the composite paleogeographic map for maximum regressive facies (Figure 56). The northern part of the area was also a topographic high during the fifth-order regressive sequence with topographic lows being found in the central and southwestern parts of the study area. Overall, topography appears to have had a greater influence on sedimentation in the regressive sequence of the Threemile fifth-order T-R unit.

Structural Controls on Wreford Deposition

The major structural elements which lie within the area of investigation include the Nemaha anticline, Irving syncline, and the Abilene anticline (Figure 11). The Nemaha anticline is cut by numerous northwest-trending high-angle normal, reverse, and strike-slip faults forming a series of northeast-trending, faulted, domal culminations, anticlines, and pull-apart grabens. This series of structural features, forming the Nemaha tectonic zone (Berendson and Blair, 1986), cuts across the eastern part of the study area from northeastern Pottawatomie County to southeastern Geary and southwestern Wabaunsee Counties (Figures 57, and 58).

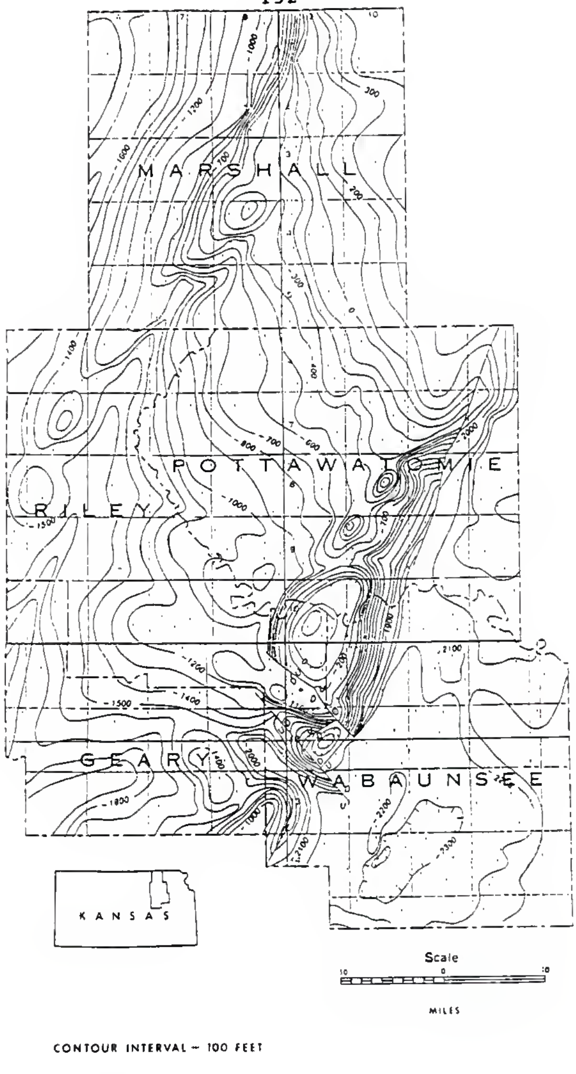

Figure 57. Structure contour map of the top of the Precambrian rocks within the area of investigation (from Cole, 1976).

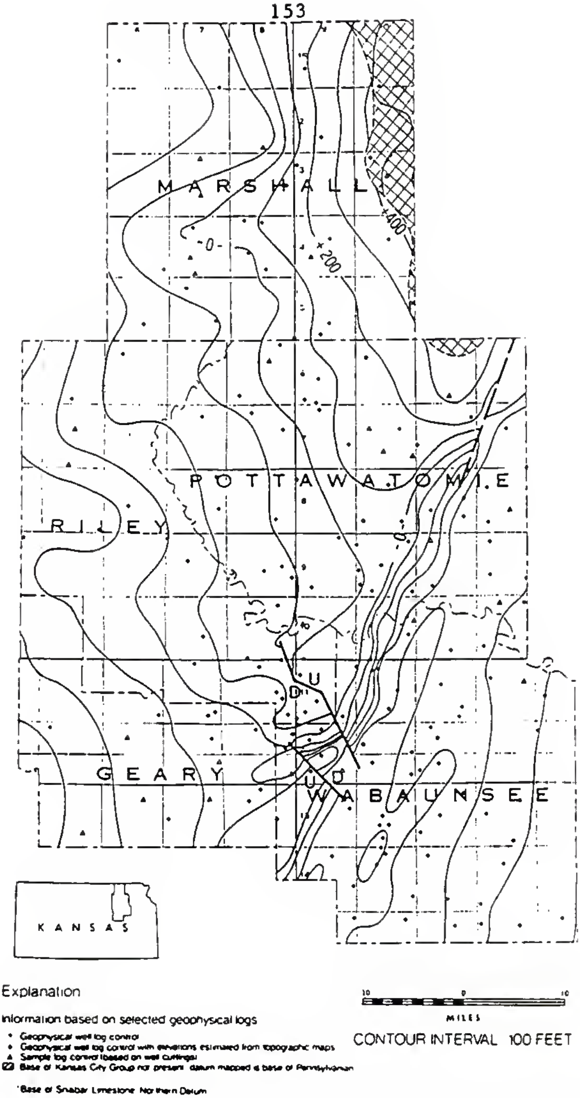

Figure 58. Structure contour map of the base of the Kansas City Group within the area of investigation (from Watney, 1978).

Bordering the Nemaha anticline to the east, in the southeast corner of the study area, is the Brownville syncline (Berendson and Blair, 1986). To the west of the Nemaha anticline, in the northwest corner of the study area, is the Abilene anticline. The Irving syncline (north-central to southwest parts of the study area) separates the Abilene anticline from the Nemaha anticline. All of these major structural features are conspicuously oriented in a northeast-southwest direction. These structures were deformed throughout the Phanerozoic Eon, with the major motion occurring at the end of the Mississippian (Berendson and Blair, 1986), and they are considered to be foreland expressions of the Pennsylvanian Ouachita orogeny to the south.

Using the top of the argillaceous (shallow intertidal) calcarenite at the top of sixth-order T-R unit W1.3 (genetic aurface W1.4) as a paleosea-level datum, paleostructure-contour maps were drawn to show relief on genetic surfaces W1.2 and W1.3 (base of sixth-order T-R units W1.2 and W1.3; Figures 59, and 60). These paleostructure contour maps show the same basic structural highs and lows, though less conspicuously, as those seen on the present-day stucture contour maps for the top of the Precambrian basement rocks (Figure 57) and the base of the Pennsylvanian Kansas City Group (Figure 58).

The influence of these structures (i.e., Nemaha

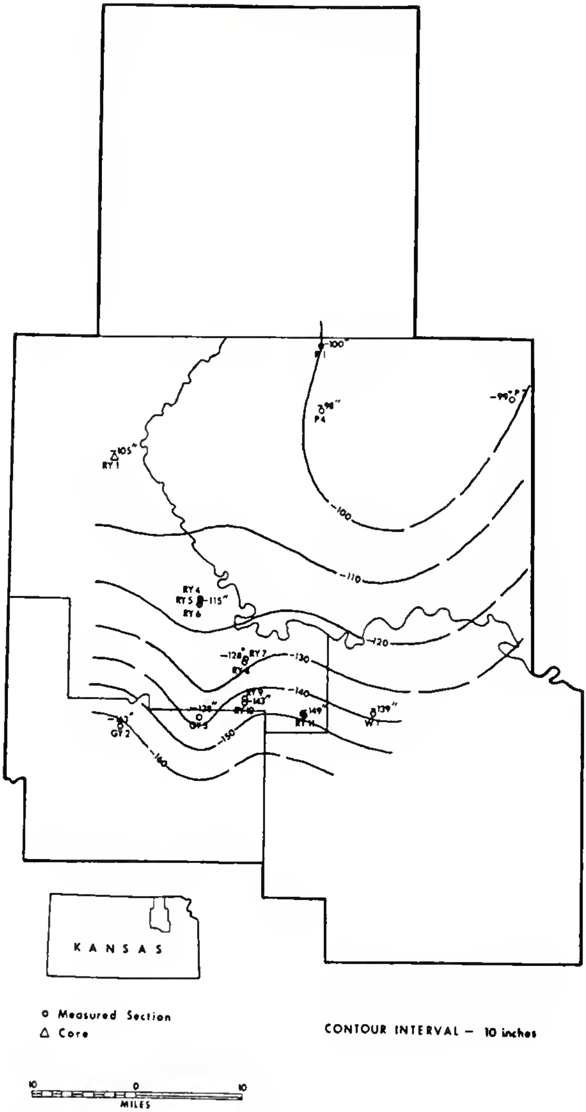

Figure 59. Paleostructure contour map of the base of sixth-order T-R unit W1.2.

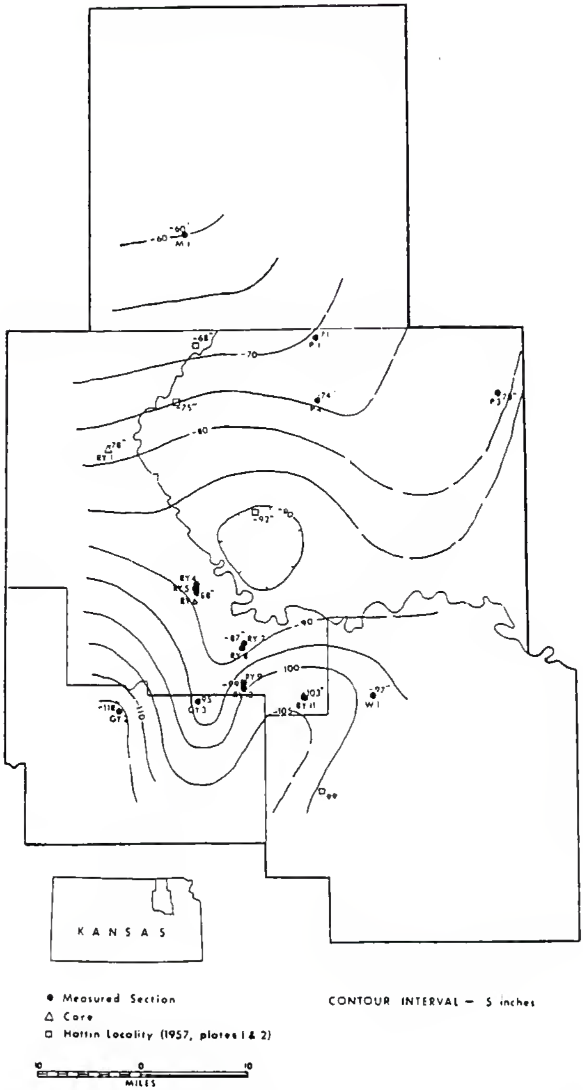

Figure 60. Paleostructure contour map of the base of sixth-order T-R unit W1.3.

anticline, Irving syncline, Abilene anticline, and Brownville syncline) on the deposits in the Wreford Limestone is readily seen in the isopach maps for the sixth-order T-R units. Comparison of isopach maps with structure contour maps shows a general correlation between structural highs and thinning of sixth-order T-R units, and between structural lows and thickening of sixth-order T-R units. Some isopach maps (e.g., sixth-order T-R units W1.4, and W1.5, Figures 45 and 48) also exhibit the same northwest and northeast trends characterizing the structural features of northeastern Kansas.

Facies changes observed during maximum transgression and regression for each of the sixth-order T-R units also appear to be influenced by structure. Both composite paleogeographic maps show recurrent facies changes in the southern part (Figures 55 and 56) of the study area and on the maximum regression composite map in west-central Riley County (Figure 56). In those paleogeographic maps showing both marine and non-marine (supratidal or alluvial) facies, those facies representing marine deposits commonly coincide with structural lows, and the subaerial deposits commonly overlie structural highs. For example, during maximum regression for sixth-order T-R units W1.5-W1.7 the geographic extent of the shallow marine facies (central and southwestern parts of the study area (Figures 47, 50, and 53) coincides with a structurally low region associated with the Irving

syncline. On these same maps, supratidal and alluvial deposits found in the northwest and northeast parts of the study area lie directly over structural highs associated with the Abilene and Nemaha anticlines, respectively.

An area along which numerous facies changes take place in southern Riley and northern Geary counties (Figures 55 and 56), may have been influenced by a less conspicuous structural feature. On the structure contour map of the top of the Precambrian rocks (Figure 57) there is a structural "drop-off", where east-west trending contours drop from a negative 11 to 12 hundred feet in southern Riley County to a negative 15 to 16 hundred feet in northern Geary County. This same structural drop-off is seen in both structure contour maps for genetic surfaces W1.2 and W1.3 (Figures 59 and 60). Most sixth-order T-R units show an overall thickening where this structural drop-off occurs. A "ridge-like" topographic high appears to have developed on the edge of this structural feature during deposition of the Wreford sediments. North of this feature, throughout the transgressive part of the Threemile fifth-order T-R unit, there is an overall shallowing of marine facies. During the fifth-order regressive sequence (sixth-order T-R units W1.5-W1.7) numerous facies changes to shallower conditions occur over this structure (Figures 55 and 56).

Similar facies changes (to shallower conditions) are commonly found in the southeast corner of Riley County

(locality RY11) and northwestern Wabaunsee County (locality W1). This part of the area lies directly over the Nemaha Anticline. Locality RY11 lies within a graben formed by two high-angle northwest-trending faults cutting across the Nemaha Anticline (Figures 57 and 58). Despite being located over the down-thrown side of these faults, the southeast corner of Riley County (i.e., locality RY11) is still structurally higher, in general, than areas to the west and south. This may account for the numerous facies changes to shallower conditions at locality RY11. The southern fault forming this graben (in Figure 57) is located between localities RY9 and GY3 and may have influenced the abrupt changes in thickness seen in sixth-order T-R units W1.4 and W1.5 going from localities RY9 and RY11 to locality GY3.

In summary, deposition of the Wreford sediments was effected by both major and minor structural elements. These structural features influenced topographic highs and lows, which in turn affected both the thicknesses and depositional environments of the sediments within the Wreford Limestone.

Diagenetic Alteration of Wreford Facies

Theories for syngenetic, penecontemporaneous, and epigenetic origin of the chert in the Wreford limestone have been discussed by Twenhofel (1919, p.407-429; and 1950,

p.398-415) and Hattin (1957, p.99-104). Twenhofel (1919) favored a penecontemporaneous origin (original inorganic precipitation) for the origin of the chert in the Wreford Limestone. However, he (1950, p.412) later cast doubt on this theory, stating that it has not been explained why silica, once deposited in disseminated form, should go back into solution and later be reprecipitated in the form of massive chert replacing some of the limestone in which it lies. Hattin (1957, p.104) recognized two main types of chert in the Wreford Limestone: compact noncalcareous chert and layered calcareous chert. Hattin (1957) believed that the origin of compact non-calcareous chert could be explained by syngenetic precipitation, whereas the layered calcareous chert owes its presence to diagenetic alteration of silica deposited more slowly than that now represented by the non-calcareous chert.

Information obtained from field and laboratory study during this investigation suggests a diagenetic origin for the chert in the Wreford Limestone. These data suggest that the chert was formed, at least in part, through the replacement of evaporite minerals during diagensis of the Wreford sediments and possibly long after lithification of the sediments. The chert in the Wreford Limestone is limited to those sixth-order T-R units in the transgressive portion of the Threemile and Schroyer fifth-order T-R unita (e.g., sixth-order T-R units W1.2, W1.3, and W2.2).

Nearly all of the limestones in the Wreford Limestone Formation contain, with differing degrees of abundance, rosette and rectangular crystal molds. These rosette and rectangular crystal molds are particularly common in those limestones containing bedded and/or nodular chert. For example, the massive, chalky, fossiliferous limestone in the upper Threemile limestone contains (in all measured sections) abundant rosette and rectangular crystal molds, many of which are filled with pseudomorphic white opaline silica and microcrystalline quartz. These crystal molds, though scattered throughout the chalky limestone, are commonly concentrated in thin (5 to 15 cm) layers found just above or below the nodular and bedded chert layers (Figure 61). Common rosette crystal molds and "ghosts", partially to completely filled with chert (Figure 62), are found within the chert beds and nodules in unit 16, locality RY11 (see Appendix, p. 228). These rosette crystal molds and ghosts found within the chert were also observed, with far less frequency, at other localities (i.e., localities GY1, GY3, and RY10). At the top of measured section GY1, nodular accumulations of chert-filled rosettes (Figure 63) were found in close association (same layer) with nodular chert containing no discernable rosette crystal molds or ghosts.

The general morphology of these crystal molds suggests that they were originally formed by gypsum. This deduction is also supported by the fact that in the core at locality

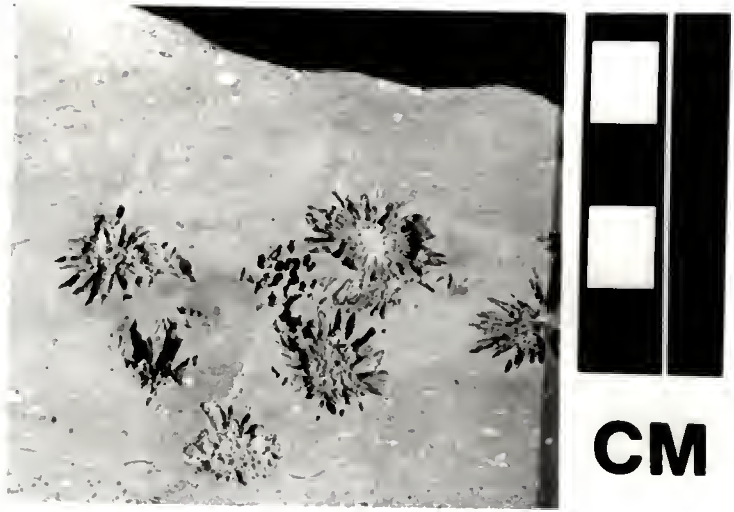

Figure 61. Photograph of rosette crystal molds partially filled with chert (sample from locality RY 10)

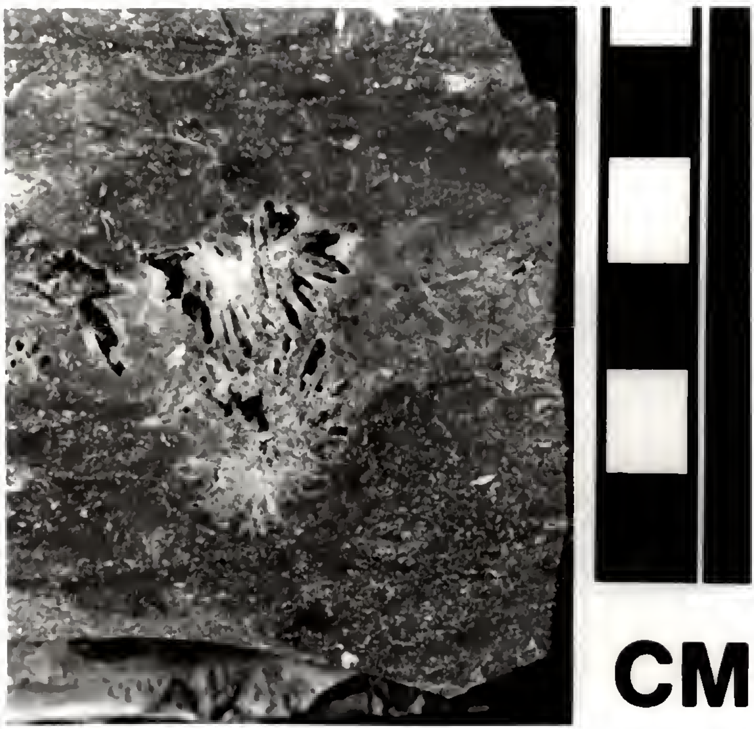

Figure 62. Photograph of rosette crystal molds and ghosts in in chert (unit 17, locality RY 11).

Figure 63. Nodular accumulation of chert filled rosettes, from the top of unit 11, locality GY 1. Scale in centimeters.

RY1, the chalky limestone (upper Threemile Limestone) contains common to abundant dark reddish gray gypsum rosettes and nodules concentrated in layers just above and below the nodular and bedded chert layers. Therefore, the vuggy appearance of this chalky limestone, in outcrop, is due to the dissolution of these gypsum rosettes and nodules. In addition, the chert filling these rosettes at locality RY11 is length-slow. Presence of length-slow fibrous silica filling these rosettes is an indication of evaporite replacement (Folk and Pittman, 1979, p. 59-72). Small patches of chalcedonic quartz in the matrix of chert nodules at locality RY11 were also found to be length-slow. The above information indicates that the chert in the Wreford Limestone, at least in part, formed as a result of evaporite replacement.

The fossil content of both chert and surrounding limestone is the same, and does not change in those areas (i.e., above and below the chert layers) rich in rectangular and rosette crystal molds. Based on fossil content, the environments of deposition for all of the cherty limestones in the Wreford Limestone Formation have been interpreted as open (subtidal) marine. In the chalky limestone (discussed above), for example, the fossils include abundant fenestrate bryozoan fronds, sparse to common whole (articulated) Composita and Enteletes, brachiopod shell fragments, and sparse productid spines, echinoids, crinoids, and ostracodes.

This indicates that open marine (subtidal) conditions existed during the deposition of this limestone. The presence of evaporites in this limestone is contradictory to this paleoenvironmental interpretation. Evaporites would not have formed in such an environment of normal salinity that supported a relatively diverse fauna. Therefore, the evaporites must have been formed after the deposition of the sediments. It is reasoned that the evaporites formed during the early diagenetic history of the sediments, before compaction took place. Draping of faint stratification around some rosettes (Figure 64), supports the idea that evaporites were formed prior to significant compaction.

Chert is found almost solely within the limestones (e.g., sixth-order T-R units W1.2, W1.3, and W2.2), major constituents of which are bryozoan and brachiopod shell fragments. Thin section analysis of the limestones surrounding the massive chert nodules and beds shows that the bryozoans, and to a lesser degree, the brachiopod shell fragments are preferentially replaced by chert. Chert content of the limestones, outside of the massive nodular and bedded chert zones, is three to four percent on the average (based on thin-section analysis). Silicified bryozoan fragments account for the vast majority of this chert. Silicified brachiopod shell fragments with minute amounts of silicified matrix make up the remainder of the chert. This preferential silicification of bryozoans might be attributed

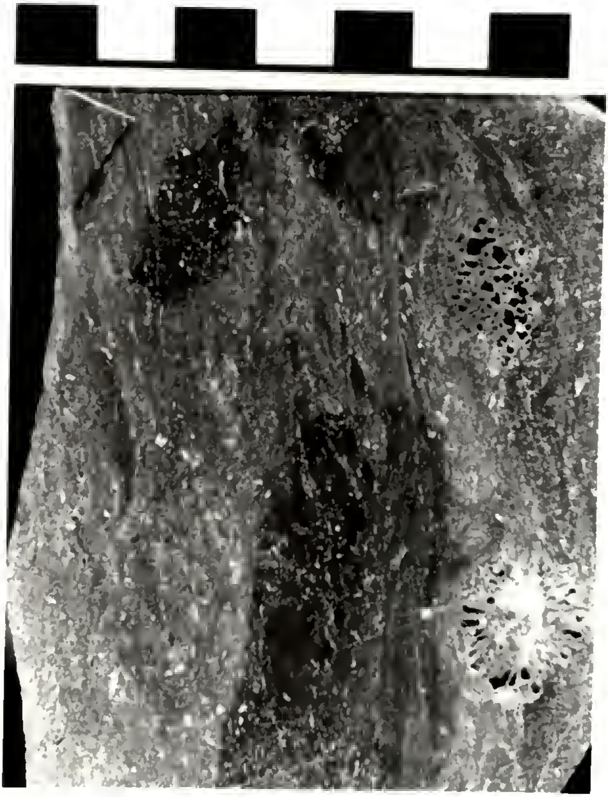

Figure 64. Photograph of rosettes in chert (sample from unit 17, locality RY 11). Note faint draping of stratification around rosettes.

to stability of the original shell mineralogy and the primary porosity of bryozoan colonies. The fact that all limestones containing massive chert (nodular or bedded chert) also contain common to abundant bryozoans, suggests that the abundance of bryozoan fragments may have been instrumental in providing suitable porosity and permeability necessary for silica saturated pore waters to infiltrate the rock.

It is believed that the chert replacing the evaporite crystals in many instances (e.g., chert sample in Figure 62) acted as a nucleus for further silicification of the surrounding limestone. The presence of numerous bryozoan and brachiopod shell fragments in the limestone surrounding chert nodules helped to facilitate this silicification process. In this way, the positioning of chert beds within the limestone is dictated by the presence of evaporites and biomoldic porosity.

From the above information, a general sequence of events can be deduced, which led to the development of chert in the Wreford Limestone (Table 2). The process of chert production has been split into four basic parts (Table 2). In general, the first part consists of the deposition and lithification (cementation) of sediments in a sixth-order T-R unit (e.g., sixth-order T-R unit W1.1). Two steps are involved, these include: 1) sediment accumulation in normal marine environments; and 2) carbonate cementation of sediments to acclude porosity and permeability.

PART I: Deposition of a sixth-order T-R unit, T-R unit I.

1. Sediment accumulation in normal marine environments
2. Carbonate cementation to acclude porosity and permeability

PART II: Deposition and diagenesis of chert-bearing sixth-order T-R unit, T-R unit II.

1. Sediment accumulation in normal marine environments
2. Infiltration of sediments by hypersaline pore fluids (due to coastal progradation and groundwater evaporation) with subsequent crystallization of evaporite minerals (i.e., euhedral-crystals, rosettes, and nodules of gypsum) producing primary lithification
3. Infiltration of pore fluids saturated with respect to silica:
   - A. partial dissolution of evaporites
   - B. precipitation of quartz polymorphs (e.g., chert) and final lithification

PART III: Deposition of superjacent sixth-order T-R unit, T-R unit III.

1. Sediment accumulation in normal marine environments
2. Compaction and cementation of T-R unit III.

PART IV: Dissolution of evaporites in modern surface and near-surface intervals of the Threemile, removal of remaining gypsum has occurred due to dissolution by late Cenozoic groundwater and surface water. Precipitation of minor amounts of alpha-quartz in fractures and crystal molds has occurred concomitant with this phase of alteration.

Table 2. General outline of the chert forming process in the Wreford Limestone Formation.

The second part of the process consists of deposition and diagenesis of the chert-bearing sixth-order T-R unit (e.g., sixth-order T-R units W1.2 and W1.3). This second part involves three steps. These are: 1) sediment accumulation in normal marine environments; 2) infiltration of sediments by hypersaline pore fluids and subsequent crystallization of evaporite minerals (i.e., euhedral-crystals, rosettes, and nodules of gypsum) producing primary lithification; and 3) infiltration of pore fluids saturated with respect to silica leading to partial dissolution of evaporites and precipitation of quartz polymorphs (e.g., chert) producing final lithification. The second step (infiltration of hypersaline pore fluids) may have resulted from coastal progradation and groundwater evaporation. Absence of chert in the sixth-order T-R units immediately above the chert-bearing sixth-order T-R units (e.g., W1.3) may indicate that step 3 (infiltration of silica-saturated pore fluids and chert replacement) took place before and/or during deposition of the sediments in the superjacent sixth-order T-R unit (e.g., W1.4). Conditions which produce mixing of normal marine waters (unsaturated with respect to calcite) and meteoric groundwater (saturated with respect to silica) may have facilitated the precipitation of such "mixing zone" cherts (Knauf, 1979). Such conditions probably developed during sixth-order transgressions of superjacent sixth-order T-R units. For example, such mixing zone conditions currently

exist over an area of many thousands of square kilometers on the Yucatan Peninsula of Mexico (Back and Hanshaw, 1970), in association with the present sixth-order transgression. The widespread occurrence of this modern mixing zone is also analogous to the widespread occurance of cherts in the Wreford Limestone.

The third part of the chert forming process includes the deposition and lithification of a superjacent sixth-order T-R unit (e.g., W1.4). Two steps are involved, these include: 1) sediment accumulation in normal marine environments; and 2) compaction and cementation of sediments.

A fourth part to the chert forming process (in the Wreford Limestone Formation) may also be added. This fourth part would include dissolution of evaporites in modern surface and near-surface intervals of the Wreford Limestone. Removal of remaining gypsum has occurred due to dissolution by late Cenozoic groundwater and surface water. Precipitation of minor amounts of alpha-quartz in fractures and crystal molds has occurred concomitant with this phase of alteration. Silica for this phase may be derived from the solution of late Cenozoic opal phytoliths (West, Barrett, and Twiss, 1987).

Though somewhat generalized, this sequence of events is believed to be a relatively accurate summation of the major events which led to the development of chert in the Wreford Limestone. It is presented as a general framework from which more detailed geochemical investigations can follow.

CONCLUSIONS

Analysis of the Wreford Limestone Formation (Lower Permian, Gearyan) in northeastern Kansas, using a hierarchal genetic (T-R unit) stratigraphic approach (i.e., after Busch and West, 1987), has made it possible to interpret sea-level changes on a much finer scale than was previously possible. The study interval, extending from the upper Spieser Shale to the middle Schroyer Limestone (upper Council Grove Group), is divisible into sixth- and fifth-order T-R units. These sixth- and fifth-order T-R units are correlative over at least a 2,000 square mile area. The sixth-order T-R units are Goodwin and Anderson's (1985) Punctuated Aggradational Cycles (PACs).

The standard Wreford section, extending from the upper part of the Speiser Shale to the middle part of the Schroyer Limestone, contains nine sixth-order genetic surfaces (W1.1 thru W2.2) bounding all or parts of ten sixth-order T-R units. These sixth-order units comprise one complete fifth-order T-R unit (the Threemile fifth-order T-R unit), the upper part of a subjacent fifth-order T-R unit (the Funston fifth-order T-R unit), and the lower part of a superjacent fifth-order T-R unit (the Schroyer fifth-order T-R unit).

The Threemile fifth-order T-R unit has an average thickness of 10 m and consists of seven sixth-order T-R units

(W1.1 thru W1.7) with thicknesses of from 0.3 m to 2.5 m. The Threemile fifth-order T-R unit probably represents a time interval of about 300,000-500,000 years (Busch and West, 1987), so the sixth-order T-R units represent time intervals of about 43,000-71,000 years. Sixth-order T-R units W1.1-W1.4 form the Threemile fifth-order transgressive sequence with sixth-order T-R unit W1.4 representing the fifth-order transgressive apex. Sixth-order T-R units W1.5-W1.7 represent the Threemile fifth-order regressive sequence.

Paleoenvironmental maps for times of both maximum transgression and regression of each sixth-order T-R unit of the Threemile fifth-order T-R unit illustrate the gradual (shallowing-upward) paleoenvironmental change between genetic surfaces and the episodic (i.e., environmentally disjunct) changes at genetic surface boundaries. These paleogeographic maps also illustrate the development of the Threemile fifth-order T-R unit as a sequence of sixth-order T-R units . Overall trends, revealed by these paleogeographic maps, include: (1) an overall shallowing of facies to the north; (2) shallowing of facies in parts of southern and southeastern Riley, northern Geary, and northwestern Wabaunsee counties during the Threemile fifth-order regressive sequence; (3) an overall deepening of facies in the central and southwestern parts of the study area during the Threemile fifth-order regressive sequence; and (4) an overall increase in the thickness of the sixth-order T-R

units in the southern and southeastern parts of the study area. Only at the top of the Threemile fifth-order T-R unit (sixth-order T-R units W1.6 and W1.7) do the sixth-order T-R units thicken to the north.

Deposition of the Wreford sediments was effected by both major and minor structural elements. Structural features influenced topographic highs and lows, which in turn effected both the thickness and depositional environments of the sediments within the Wreford Limestone. For example, thinning of sixth-order T-R units and shallowing of facies took place over structural highs in the northeast, northwest, and southern parts of the study area. Thickening of sixth-order T-R units and deepening of facies generally corresponded to structural lows.

Field and labratory data indicate a diagenetic origin for the conspicuous nodular and bedded chert found within the Wreford Limestone. It is suggested that much of the chert formed as a result of evaporite replacement. The evaporites themselves are secondary in origin, forming in the sediments after deposition and before compaction. The chert forming process is divided into three major parts. The first part includes deposition and lithification (carbonate cementation) of a subjacent sixth-order T-R unit (containing no evaporites or chert). The second part of the chert forming process consists of the deposition and diagenesis of chert-bearing sixth-order T-R units. Included in this second part are three

steps, these are: 1) sediment accumulation in normal marine environments: 2) infiltration of sediments by hypersaline pore fluids and subsequent crystalization of evaporite minerals producing primary lithification; and 3) infiltration of pore fluids saturated with respect to silica leading to partial dissolution of evaporites and precipitation of quartz polymorphs (e.g., chert) producing final lithification. The third part of the chert forming process includes deposition and lithification (compaction and cementation) of a superjacent sixth-order T-R unit (containing no chert).

REFERENCES

Adams, J.E., Cheney, M.G., Deford, R.K., Dickey, R.I., Dunbar, C.O., Hills, J.M., King, R.E, Lloyd, E.R., Miller, A.K., and Needham, C.E., 1939, Standard Permian section of North America: Amer. Assoc. of Petroleum Geol., Bull., v. 23, p.1673-1681.

Anderson, E.J., 1971, Environmental models for paleozoic communities: Lethaia, v. 4, p.297-302.

--------------, and Goodwin, P.W., 1980, Application of the PAC hypothesis to limestones of the Helderburg Group: Soc. Econ. Paleont. and Mineral., Mid-Continent Section, p.1-22.

Back, W., and Hanshaw, B.B., 1970, Comparison of chemical hydrology of the carbonate peninsulas of Florida and Yucatan: Journal of Hydrology, v. 10, p.330-368.

Berendson, P., and Blair, K.P., 1986, Subsurface structural maps over the Central North American rift system (CNARS), central Kansas, with discussion: Kansas Geol. Survey, Subsurface Geology Series 8, 16 p.

Bifano, F.V., Guber, A.L., and Cuffey, R.J., 1974, Ostracode paleoecology in shales of the Wreford Megacyclothem (Lower Permian; Kansas and Oklahoma): Geol. Soc. Amer., Abstr. Programs, v. 6, p. 492.

Bogina, M.A., 1988, Hierarchal genetic stratigraphy of the Neva Limestone and Eskridge Shale (Early Permian, Wolfcampian Age) of Northeastern Kansas: Geol. Soc. Amer., Abstr. Programs, v. 20, no. 2, p. 91.

Branson, C.C., 1960, Proposed American standard of early Permian(?) rocks--a century-old controversy: Okla. Geol. Notes, v. 20, p. 229-235.

Bretsky, P.W., Jr., 1969, Central Appalachian Late Ordivician communities: Geol. Soc. Amer. Bull., 80, p. 193-212.

------------------, 1970, Upper Ordivician ecology of the central Appalacians: Peabody Mus. Nat. Hist. 34, 133 p.

------------------, and Lorenz, D.M., 1970, An essay on genetic-adaptive strategies and mass extinctions: Geol. Soc. Amer. 81, p. 2449-2456.

Brezenski, D.K., 1981, Conodont distribution, lithofacies, variations, and community response in the Ames (Pennsylvanian) marine-event: M.S. thesis, Univ. of Missouri, 63 p.

---------------, 1983, Depositional model for an Appalachian Pennsylvanian marine incursion: Northeast. Geol., 5, p. 92-99.

Busch, R.M., 1984, Stratigraphic analysis of Pennsylvanian rocks using a hierarchy of transgressive-regressive units [Ph.D. Dissertation]: Univ. of Pittsburgh, Pittsburgh, Pennsylvania, 427 p.

-----------, 1988, Minor T-R units in the Lower Permian Chase Group, Northeast Kansas: Geol. Soc. America Centinnial Field Guide, edited by Hayward, O.T., Geol. Soc. Amer., Boulder, Co., p. 17-24.

-----------, Bogina, M. A., and Clark, M.H., 1988, Preliminary report on the genetic stratigraphy of the Hamilton, Kansas, fossil localities--Deer Creek fifth-order T-R unit, in Mapes, G., and Mapes, R.H., eds., Regional geology and paleontogy of upper Paleozoic Hamilton quarry area in southeastern Kansas: Hamilton quarry guidebook, 22nd Annual Meeting South-central Section, Geol. Soc. Amer., p. 59-66.

-----------, Clark, M.H., and Bogina, M.A., 1988, Hierarchal genetic stratigraphy of the upper Pennsylvanian (Virgillian) Deer Creek Limestone Formation at the classical Hamilton, Kansas fossil quarries: Geol. Soc. Amer., Abstr. Programs, v. 20, no. 2, p. 92-93.

-----------, and Rollins, H.B., 1984, Correlation of Carboniferous strata using a hierarchy of transgressive-regressive units: Geology, v. 12, p. 471-474.

-----------, Rollins, H.B., and West, R.R., 1988, Use of hierarchal genetic (T-R unit) stratigraphy for increased chronostratigraphic and geochronologic resolution of the entire geologic record: Geol. Soc. Amer., Abstr., Programs, v. 20, no. 2, p.92.

-----------, and West, R.R., 1987, Hierarchal genetic stratigraphy: a framework for paleoceanography: Paleoceanography, vol. 2, no. 2, p. 141-164.

-----------, West, R.R., Barrett, F.J., Barrett, T.R., 1985, Cyclothems versus a hierarchy of transgressive-regressive units, in Watney, W.L., Kaesler, R.L., and Newell, K.D., eds., Recent interpretations of Late Paleozoic cyclothems: Conference Symposium, Soc. Econ. Paleont. Mineral., Mid-Continent Section, p. 141-153.

-----------, West, R.R., and Rollins, H.B., 1987, Comment and Reply on "Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along midcontinent outcrop along midcontinent outcrop belt, North America": Geology, March, p. 276-277.

Chang, K.H., 1975, Unconformity-bounded stratigraphic units: Geol. Soc. Amer. Bull., 86, p. 1544-1552.

Chaudhuri, S., 1976, The significance of Rubidium-Strontium Ages of sedimentary rock: Contrib. Mineral. Petrol. 59, p. 161-170.

-------------, and Lee, M.J., 1972, Rubidium-strontrium isotopic studies of clay minerals in the Lower Permian Havensville shale of Kansas: Geol. Soc. Amer. Abs. Prog., v. 4, no. 4, p. 277.

Chelikowsky, J.R., 1972, Structural geology of the Manhattan, Kansas, area: Kansas Geol. Survey, Bull. 204, pt. 4, 13 p.

Clark, M.H., 1988, Hierarchal genetic stratigraphy of the Lower Permian (Wolfcampian) Red Eagle Limestone and Roca Shale Formations, Northeastern Kansas: Geol. Soc. Amer., Absts. Programs, v. 20, no. 2, p. 95.

Coldiron, R.W., 1978, Acroplous vorax Hotton (Amphibia, Saurerpetontidae) restudied in light of new material: American Museum Novitates 2662, p. 1-27.

Cole, V.B., 1976, Configuration of the top of Precambrian rocks in Kansas: Kansas Geol. Survey, Map M-7.

Condra, G.E., and Upp, J.E., 1931, Correlation of the Big Blue Series in Nebraska: Nebraska Geol. Survey, Bull. 6, ser. 2, p. 7-74.

Cragin, F.W., 1896, The Permian System in Kansas: Colo. College Studies, v. 6, p. 1-48.

Cuffey, R.J., 1967, Bryozoan Tabulipora Carbonaria in the Wreford Megacyclothem (Lower Permian) of Kansas: Univ. Kans. Paleont. Contrib., Bryozoa, Article 1, 96 p.

------------, 1977, Ctenostome bryozoans and burrowing barnicles of the Wreford Megacyclothem (Lower Permian; Kansas and Oklahoma): Geol. Soc. Amer., Abstr. Programs, v. 9, p. 181-194.

Cullers, R.L., 1974, The rare-earth element distributions in the clay-size fraction of the Permian Havensville and Eskridge Shales of Kansas and Oklahoma: Geol. Soc. Amer., Abstr. Programs, p. 101.

Cullers,R.L., and Chaudhuri, S., 1975, Rare-earth distributions in clay minerals and in the clay-sized fraction of the Lower Permian Havensville and Eskridge Shales of Kansas and Oklahoma: Geochim. Cosmochim. Acta 39, 12, p.1691-1703.

deRaaf, J.F.M., Reading, H.G., and Walker, R.G., 1965, Cyclic sedimentation in the Lower Westphalian of north Devon, England: Sedimentology, v. 4, p. 1-52.

Dodin, S.F., 1974, Ecological trend of Mollusca: some faunal techniques for recognizing stress gradients: in Donahue, J., and Rollins, H.B., eds., Conemaugh (Glenshaw) marine events: Soc. Econ. Paleont. Mineral., Eastern Section Conference Guidebook, p. D1-D8.

Donahue, J., and Rollins, H.B., 1974, Paleoecological anatomy of a Conemaugh (Pennsylvanian) marine event: Geol. Soc. Amer., Special Paper 148, p. 153-170.

Dott, R.H., 1941, Regional stratigraphy of the Mid-Continent: Amer. Assoc. Petroleum Geol., Bull., v. 25, p. 1619-1705.

Dunbar, C.O., 1940, The type Permian: its classification and correlation: Amer. Assoc. Petroleum Geol., Bull., v. 24, Feb., p. 237-281.

Elias, M.K., 1934, Cycles of sedimentation in the Big Blue Series of Kansas: Geol. Soc. of Amer. Proc., Abstr., 1933, p. 366.

-----------, 1937, Depth of deposition of the Big Blue (Late Paleozoic) sediments in Kansas: Geol. Soc. Amer., Bull., v. 48, p. 403-432.

-----------, and Moore, R.C., 1934, Sedimentation cycles as a guide to stratigraphic classification of the Kansas Lower Permian: Geol. Soc. Amer. Proc., 1933, Abstr., p. 100.

Folk, R.L., 1959, Practical petrographic classification of limestones: Amer. Assoc. Petroleum Geol., Bull., v. 43, p.1-38.

----------, 1962, Sorting in some carbonate beaches of Mexico: N.Y. Acad. Sci., Trans., series 2, v. 25, p. 222-244.

Folk, R.L., and Pittman, J.S., 1979, Length-slow chalcedony: a new testament for vanished evaporites, in McBride, E.F, edt., Silica in Sediments: nodular and bedded chert: Soc. Econ. Paleont. Mineral., no. 8, p. 59-72.

Fry, H.C., and Cuffey, R.J., 1975, Bifoliate crtptostome bryozoans in the Wreford Megacyclothem (Lower Permian) in Kansas: Geol. Soc. Amer., Abstr. Programs, v. 7, no. 1, p. 61-62.

Fry, H.C., and Cuffey, R.J., 1976, Filiramoporina Kretaphilia A new genus and species of bifoliate Tubulobryozoan (Ectoprocta) from the Lower Permian Wreford Megacyclothem of Kansas: Univ. Kansas Paleont. Contrib., Paper 84, 9 p.

Goodwin, P.W., and Anderson, E.J., 1985, Punctuated aggradational cycles: A general hypothesis of episodic stratigraphic accumulation: Jour. Geology, v. 93, p. 515-533.

Goodwin, P.W., Anderson, E.J., Goodman, W.M., and Saraka, L.J., 1986, Punctuated aggradational cycles: implications for stratigraphic analysis: Paleoceanography, vol. 1, no. 4, p. 417-429.

Gragin, F.W., 1896, Observations on the Cimarronian Series: Amer. Geologist, v. 19, p. 351-363.

Grieg, P.B., 1959, Geology of Pawnee County, Oklahoma: Okla. Geol. Survey, Bull. 83, 188 p.

Habicht, J.K.A., 1979, Paleoclimate, Paleomagnetism, and Continental Drift: Amer. Assoc. Petr. Geol., Studies in Geology, no. 9, 31 p.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., Walters, R., 1982, A geologic time scale: Cambridge Univ. Press, New York, U.S.A., 131 p.

Hattin, D.E., 1957, Depositional environment of the Wreford Megacyclothem (Lower Permian) of Kansas: Kansas Geol. Survey Bull. 124, 150 p.

Hay, R., 1891, Geology of Kansas salt: Kansas State Board Agriculture, Bien. Rept. 7, v. 12, p. 94.

-------, 1893, Geology and mineral resources of Kansas: Kansas State Board Agriculture, Bien. Rept. 8, v. 13, pt. 2, p. 104.

Heckel, P.H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Midcontinent North America: Amer. Assoc. Petroleum Geol., Bull., v. 61, p. 1045-1068.

------------, 1980, Paleogeography of eustatic model for deposition of Midcontinent Upper Pennsylvanian cyclothems, in Fouch, T.D., and Magathan, E.R., eds., Paleogeography of the west-central United States: Paleogeography Symposium 1, Soc. Econ. Paleont. Mineral., Rocky Mountain Section, p. 197-215.

------------, 1985, Current view of Midcontinent Pennsyvanian cyclothems: in Watney, L.W., Kaesler, R.L., and Newell, eds., Recent interpretations of Late Paleozoic cyclothems: Soc. Econ. Paleont. Mineral., Mid-Continent Section, p. 1-22.

------------, 1986, Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along midcontinent outcrop belt, North Amercan: Geology, v. 14, p. 330-334.

------------, and Baesemann, J.F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) megacyclothems in eastern Kansas and Nebraska: Kansas Geol. Survey Guidebook, ser. 4, p. 4-60.

------------, Brady, L.L., Ebanks, W.J., and Pabian, R.K., 1979, Field Guide to Pennsylvanian cyclic deposits in Kansas and Nebraska: Kansas Geol. Survey Guidebook, ser. 4, p. 4-60.

Hotton, N., III, 1959, Acroplous vorax, a new and unusual labyrinthodont amphibian from the Kansas Permian: Joun. of Paleont. 33, p. 161-178.

Jewett, J.M., 1933, Evidence of cyclic sedimentation in Kansas during the Permian Period: Kansas Acad. Sci. Trans., v. 36, p. 137-140.

------------, 1941, The geology of Riley and Geary Counties, Kansas: Kansas Geol. Survey, Bull. 39, p. 1-64.

------------, 1959, Graphic column and classification of rocks in Kansas: Kansas Geol. Survey (wall chart).

Knauf, P.L., 1979, A model for the origin of chert in limestone: Geology, v. 7, June, p. 274-277.

Laporte, L.F., 1969, Recognition of a transgressive carbonate within an epeiric sea : Helderburg Group (Lower Devonian) of New York state: Spec. Publ. Soc. Econ. Paleont. Mineral., 14, p. 98-119.

Lee, W., 1954, Earthquake and Nemaha Anticline: Amer. Assoc. Petroleum Geol., Bull., v. 38, no. 2, p. 338-340.

Lee, M.J., 1972, Clay mineralology of Havensville Shale: Geol. Soc. Amer., Abstr. Programs, v. 4, no. 4, p. 283-284.

---------, and Chaudhuri, S., 1976, Clay mineral studies of the Lower Permian Havensville Shale in Kanaas and Oklahoma: Clay and Clay Minerals, v. 24, p. 239- 245.

Leonard, K.W., 1988, Genetic stratigraphy and paleogeographic development of the Iola Limestone and Lane Shale (Missourian, Upper Pennsylvanian) of northeastern Kansas: Geol. Soc. Amer., Abst., Programs, v. 20, no. 2, p. 122.

Lutz-Garihan, A.B., 1976, Composita Subtilita (Brachiopoda) Wreford Megacyclothem (Lower Permian) in Nebraska, Kansas and Oklahoma: Univ. Kansas Paleont. Contrib., Paper 81, p. 1-18.

------------------, and Cuffey, R.J., 1979, Stratigraphy of the Lower Permian Wreford Megacyclothem in southernmost Kansas and northern Oklahoma: Kansas Geol. Survey, Bull. 216, 19 p.

Meek, F.B., and Hayden, F.V., 1860, Geological explorations in Kansas Territory: Acad. Nat. Sci. Philadelphia Proc., 1859, p. 16.

Middleton, G.V., 1973, Johannes Walther's law of the correlation of facies: Geol. Soc. Amer., Bull., v. 84, p. 979-988.

Moore, G.E., 1979, Pennsylvanian paleogeography of the southern Mid-Continent, in N.J., Hyne, ed., Pennsylvanian sandstones of the Mid-Continent: Tulsa Geological Society Spec. Pub. 1, p. 2-12.

Moore, R.C., 1936, Pennsylvanian and Lower "Permian" rocks of Kansas-Missouri region: Kansaa Geol. Soc., 10th Field Conf. Guidebook, p. 7-73.

-----------, 1949, Introduction to historical geology, 1st ed.: New York, McGraw-Hill Book Company, 582 p.

Mudge, M.R., Burton, R.H., 1958, Geology of Wabaunsee County, Kansas: U.S. Geol. Survey Bull. 1068, 210 p.

Newton, G.B., 1971, Rhabdomesid bryozoans of the Wreford Megacyclothem (Wolfcampian, Permian) of Nebraska, Kansas, and Oklahoma: Univ. Kansas Paleont. Contrib., Bryozoa 2, Article, 71 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: Amer. Assoc. Petroleum Geol., Bull., v. 67, no. 5, May, p. 841-875.

O'Conner, H.G., 1963, Changes in Kansas stratigraphic nomenclature: Amer. Assoc. Petroleum Geol., Bull., v. 47, no. 10, p.1873-1877.

Prosser, C.S., 1895, Classification of Upper Paleozoic rocks central Kansas: Jour. Geology, v. 3 p. 682-705.

Ramsbottom, W.H.C., 1979, Rates of transgression and regression in the Carboniferous of northwest Europe: Jour. Geol. Soc. London, 136, p. 147-153.

Raup, D.M., and Stanley, S.M., 1975, Principles of Paleontology, 2nd ed., W.H. Freeman and Company, San Francisco, 481 p.

Rickard, L.V., 1962, Late Cayugan (Upper Silurian) and Helderburgian (Lower Devonian) stratigraphy in New York: N.Y. State Mus. and Sci. Serv., Bull. 386, 157 p.

Rollins, H.B., West, R.R., and Busch, R.M., 1988, Hierarchal genetic stratigraphy: implications for the paleobiological record: Geol. Soc. Amer., Abst., Programs, v. 20, no. 2, p. 127.

Roscoe, B., and Adler, F.J., 1983, Permo-Carboniferous hydrocarbon accumulations, Mid-Continent, U.S.A.: Amer. Assoc. Petroleum Geol., Bull., v. 67, no. 6, June, p. 979-1001.

Ross, C.A., and Ross, J.R.P., 1985, Late Paleozoic depositional sequences are synchronous and worldwide: Geology, v. 13, March, p. 194-197.

Sanders, H.L., 1969, Benthic marine diversity and the stability time hypothesis, Diversity and stability in ecological systems: Brookhavin Symposia in Biology, no. 22, p. 71-81.

Sanderson, G.A., and Verville, G.J., 1970, Morphologic variability of the genus Schwagerina in the Lower Permian Wreford Limestone of Kansas: Paleontology, v. 13, Part 2, p. 175-183.

Schoewe, W.H., 1949, The geography of Kansas: Kansas Acad. Sci. Trans., v. 52, p. 276.

Schultze, H.P., 1985, Marine to on shore vertebrates in the Lower Permian of Kansas and their paleoenvironmental implications: Univ. Kansas Paleont. Contr., Paper 113, p. 1-16.

Shenkel, C.W., 1959, Geology of the Abilene Anticline in Kansas: Kansas Geol. Society 24th Field Conference Guidebook, p.116-128.

Simonson, A.H., and Cuffey, R.J., 1980, Fenestrate, pinnate, and ctenostome bryozoans and associated barnicle borings in the Wreford Megacyclothem (Lower Permian) of Kansas, Oklahoma, and Nebraska: Univ. Kansas Paleont. Contr., Paper 101, p.25-36.

Somerville, I.D., 1979, Minor sedimentary cyclicity in late Asbian (upper D1) limestones in the Llangollen district of North Wales: proc. Yorks. Geol. Soc., 42, p.317-341.

Stevens, C.H., 1971, Distribution and diversity of Pennsylvanian marine faunas relative to water depth and distance from shore: Lethaia, v. 4, p.403-412.

Suchy, D.R., 1987, Sixth-order transgressive-regressive units in the Fort Scott cyclothem of southeast Kansas: Geol. Soc. Amer., Abst., Programs, v. 19, no. 3, p.178.

Sutton, R.G., Bowen, Z.P., and McAlester, A.L., 1970, Marine shelf environments of the Upper Devonian Sonyea Group of New York: Geol. Soc. Amer., 81, p.2975-2992.

Swallow, G.C., 1866, Preliminary report of the geology of Kansas: Lawrence, p.11-16.

Twenhofel, W.H., 1919, The chert of the Wreford Foraker Limestones along the state of Kansas and Oklahoma: Amer. Jour. Sci., ser. 4, v. 47, p.407-429.

---------------, 1950, Principles of sedimentation: McGraw Hill, New York, 2nd. ed., p. 350-382, 398-415.

Underwood, J.R., and Polson, A., 1988, Spillway fault system, Tuttle Creek reservoir, Pottawatomie County, northeastern Kansas, in Hayward, O.T., ed., South-Central section of the Geological Society of America centennial field guide volume 4: Geol. Soc. Amer., p. 11-16.

Vail, P.R., Mitchum, R.M., Jr., and Thompson, S., III, 1977, Seismic stratigraphy and global changes of sea level, 4, global cycles of relative sea level: Amer. Assoc. Petroleum Geol., Mem. 26, p. 83-97.

Walker, K.R., and LaPorte, L.F., 1970, Congruent fossil communities from Ordivician and Divonian carbonates of New York: Jour. Paleont. 44, p. 928-944.

Walker, R.G., 1984, Facies models, second edition: publ. by Geol. Assoc. Canada, Geoscience Canada, Reprint Series 1, 311 p.

Walters, K.L., 1954, Geology and ground water resources of Marshall County, Kansas: Kansas Geol. Survey, Bull. 106, p. 107.

Wanless, H.R., and Weller, J.M., 1932, Correlation and extent of Pennsylvanian cyclothems: Geol. Soc. Amer., Bull., v. 43, p. 1003-1016.

Warner, D.J., and Cuffey, R.J., 1973, Fistulaporacean bryozoans of the Wreford Megacyclothem (Lower Permian) of Kansas: Univ. Kansas Paleon. Contr., Paper 65, p. 1-24.

Watney, W.L., 1978, Structural contour map base of Kansas City Group (Upper Pennsylvanian), eastern Kansas: Kansas Geol. Survey, Map M-10.

Weller, J.M., 1930, Cyclic sedimentation of the Pennsylvanian Period and its significance: Jour. Geol., v. 38, p. 97-135.

Wells, K.E., 1985, Detailed correlation of the Woodsrun marine unit (Late Pennsylvanian) in southwestern Pennsylvania: Masters Thesis, Univ. Pittsburgh, Pa., 71 p.

West, R.R., Barrett, T.R., and Twiss, P.C., 1987, Chert in the Lower Permian of the northern midcontinent: Geol. Soc. Amer., Abst. Prog., v. 19, no. 3, p. 87.

----------, and Busch, R.M., 1985, Sixth-order transgressive-regressive units in the Wewoka Formation (Anna Shale Member) of Oklahoma, in, Watney, W.L., Kaesler, R. L., and Newell, K.D., eds., Recent interpretation of Late Paleozoic Cyclothems: Soc. Econ. Paleont. and Mineral., Mid-Cont. Sect., Lawrence Kansas, p. 155-170.

Wright, V.P., 1981, A subaerial stromatolite from the Lower Carboniferous of South Wales: Geol. Mag., 118, p. 97-100.

Zeller, D.E., ed., 1986, The statigraphic succession in Kansas: Kansas Geol. Survey Bull. 189, 81 p.

APPENDIX

Measured Sections

This appendix contains descriptions of the twenty measured sections used in this study. The measured sections include descriptions of all lithologic changes, thicknesses of beds, and the locations of outcrops. In addition, the boundaries between fifth-order T-R units and sixth-order T-R units are delineated.

The letters "TA" were placed at the end of those units, in each sixth-order T-R unit (within the Threemile fifth-order T-R unit), representing maximum transgression. These units were utilized in producing the paleogeographic maps representing maximum transgression for each sixth-order T-R unit. The facies representing maximum regression, within each sixth-order T-R unit, is simply the facies at the top of the T-R unit.

State: KS County: Geary Quadrangle Junction City

Locality Description:

Road and stream cuts on the north side of Interstate Highway 70 where it crosses over Smokey Hill River, NW¼, NE¼, Sec. 7 T. 12, R. 5 E.

Section GY1

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	ft	in	m
THREEMILE	W1.3	11. Threemile Limestone: light gray, weathers pale yellow-orange, skeletal, coarse calcilutite (wackestone); massive, blocky, moderate to well indurated, chalky, porous with common solution pits and vugs, common rectangular and rosette crystal molds, occasional nodular accumulations of rosette crystal molds filled with white to milky white chert at top of unit; Chert; 3 zones; 5 in. thick layer of bedded chert at base of unit; dark gray and dark blue-gray to white, occasionally mottled, fossiliferous same as limestone; two layers of nodular chert one 16 in. (1 in. thick) from base and one at top (2 in. thick), dark gray centers grading outward to very light gray and white, fossiliferous same as limestone, upper nodular chert bed found in same layer as nodular accumulations of chert filled rosettes; fossils: common fenestrate and sparse ramose bryozoa, brachiopod shell fragments, crinoids, echinoids, productid spines, ostracodes, and rare Composita.	2	2	0.66
		10. Threemile Limestone: medium gray, weathers pale yellow-orange, skeletal, coarse calcilutite to calcarenite; nonbedded, blocky, argillaceous, well indurated, occasional to common rosette and rectangular crystal molds; fossils: crinoids, fenestrate and ramose bryozoa, Composita, Reticulatia, productid spines, echinoids, and ostracodes.	0	6	0.1[illegible]
		9. Threemile Limestone: green-gray and dark gray (mottled), shale; shaly bedded, platy, very calcareous, occasional shell hash lenses, occasional rosette crystal molds; very fossiliferous with Derbyia, Composita, Reticulatia, Neochonetes, crinoids, fenestrate and ramose bryozoa, sparse echinoids, productid spines, Straparolus, ostracodes, trilobites fragments, and rare Aviculopecten, most specimens are large (robust) in form and commonly articulated. TA	0	8	0.2[illegible]
	W1.2	8. Threemile Limestone: light gray, weathers pale yellow-orange, skeletal, coarse calcilutite to fine calcarenite; massive, blocky, well indurated, common rectangular crystal molds in lower 4 in., sparse small limestone intraclasts at top of unit; Chert; 2 zones, one layer bedded chert (4 in. thick), 20 in. from base of unit; dark gray and dark blue-gray to very light gray and white, occasionally mottled, fossiliferous same as limestone; one layer nodular chert (1.5 in. thick) 27 in. from base; dark gray centers grading outward to very light gray and white, fossiliferous same as limestone; fossils: fenestrate and sparse ramose bryozoa, brachiopod shell fragments, productid spines, sparse Composita, crinoids echinoids, and ostracodes.	2	7	0.7[illegible]
		7. Speiser Shale: green-gray shale; shaly bedded, platy, calcareous, moderate induration; sparsely fossiliferous with Aviculopecten, brachiopod shell fragments, Enteletes, small bryozoa fragments, and ostracodes.	0	3	0.08

Section GY1 continued

THREEMILE	W1.2	6. Speiser Shale: green-gray shale; shaly bedded, platy, very calcareous to calcareous (at top), moderate to well (at base) indurated, occasional shell hash lenses; very fossiliferous with abundant crinoids, fenestrate and ramose bryozoa, common _Reticulatia_, chonetids, _Composita_, sparse _Straparolus_, _Enteletes_(?), productid spines, _Aviculopecten_, ostracodes, _Derbyia_, and rare trilobite fragments, most specimens large (robust) in form and articulated. TA	0	10	0.25
	W1.1	5. Speiser Shale: green-gray shale; shaly bedded, platy, moderate induration, calcareous; sparsely fossiliferous with common _Orbiculoidea_, sparse _Aviculopecten_, productid shell fragments and spines, Straparolus, and ostracodes.	0	2.5	0.06
		4. Speiser Shale: green-gray shale; shaly bedded, platy, moderate induration, calcareous; fossiliferous with Aviculopecten, productid shell fragments and spines, and ostracodes.	1	4	0.41
		3. Speiser Shale: light green-gray, skeletal, coarse calcarenite to fine calcirudite; nonbedded, blocky, common to locally abundant granular-sized limestone and shale intraclasts, argillaceous and slightly sandy; fossils: abundant ostracodes, and bivalve shell fragments. TA	0	5	
		2. Speiser Shale: green-gray, shale; shaly bedded, flaggy, sandy, calcareous, moderate induration; fossiliferous with abundant ostracodes and sparse to rare shell fragments.	0	6	
FUNSTON		1. Speiser Shale: olive green claystone; nonbedded, blocky, well indurated, sandy, calcareous, with common orangish green root mottles; unfossiliferous.	1	4	0.41

State KS County: Geary Quadrangle: Junction City

Locality Description Roadcuts along the south side of Interstate Route 70, 4 miles east of Junction City, Kansas, at 6, NE 1/4, sec. 34, T.11S., R.6E.

Section GY2

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – –Climate Change Surface	Unit Thicknesses ft	in	m
SCHROYER	W2.2	27. Schroyer Limestone: very pale yellow-orange, skeletal, calcarenite; nonbedded, fossiliferous with <u>Composita</u>, <u>Reticulatia</u>, brachiopod shell fragments, byrozoa, crinoids echinoids, and sparse <u>Aviculopecten</u>, and rare <u>Aviculopinna</u>; chert; two zones of medium to dark gray bedded chert: one 3 in, thick, 4 in. from base of unit, one 12 in. thick, 12 in. from base of unit, fossiliferous same as limestone, occasional nodules of chert found between bedded chert layers	2	7.5	0.8
		26. Schroyer Limestone: light gray to pale yellow-orange, nonbedded, well indurated, fossiliferous with <u>Composita</u>, productids, brachiopod shell fragments, bryozoa, crinoids, echinoids, and sparse bivalve shell fragments, skeletal, fine-grained calcarenite; upper 6 in. contains common nodular chert, light to dark gray, weathers very light gray, 3 in. thick layer of bedded chert 15 in. from base, light to dark gray, weathers gray to white, fossiliferous same sas limestone.	2	6	0.7
	W2.1	25. Havensville Shale: medium to dark gray, claystone; nonbedded, poorly indurated, unfossiliferous, with occasional calcite geodes.	3	8.5	1.1
		24. Havensville Shale: light gray to pale yellow-orange, skeletal, coarse calcilute to calcarenite (wackestone); thick bedded, moderately indurated; fossils: <u>Composita</u>, brachiopod shell fragments, productid spines, fenestrate bryozoa, crinoids, and ostracodes, some shell fragments are algal (Osagia?) coated. TA			
THREEMILE	W1.7	23. Havensville Shale: light yellow-brown to medium gray, shale; platy, moderately indurated, calcareous with sparse calcareous nodules; very sparsely fossiliferous with ostracodes snd rsre bivalve shell fragments.	0	6	0.15
		22. Havesville Shale: medium gray to green-grsy, shale; shaly bedded, slightly calcareous, poor to moderste induration; fossiliferous with sparse bivalve shell fragments, bryozoa fragments, and ostracodes.	2	2.5	0.67
		21. Havensville Shale: medium gray to yellowish brown, skeletal medium calcarenite; thin bedded, moderate induration, common intraclasts (up to granule size); fossils: bivalve shell fragments (<u>Avicutopecten</u>), <u>Permophorus</u>?), and ostracodes. TA	0	6	0.15
	W1.6	20. Havensville Shale: medium gray to greenish gray and yellowish gray, shale: shaly bedded, calcareous with common thin limestone lenses; fossiliferous with <u>Permophorus</u>, bivalve shell fragments, and ostracodes.	0	7	0.18
		19. Havensville Shale: light to medium gray and pale yellow-orange, skeletal, coarse calcarenite; thinly bedded, moderate to occasionally poor induration, occasional lenses of shaly material, argillaceous, sparse to locally common intraclasts (up to pebble size), some intraclasts algal (<u>Osagia</u>?) coated; fossils: <u>Aviculopecten</u>, snd ostracodes. TA	1	5	0.43

Section GY2

	W1.5	18. Havensville Shale: green-gray and yellow-gray, claystone; nonbedded, poor to moderate induration, sparse calcareous nodules, unfossiliferous.	2	0	0.61
	W1.5	17. Havensville Shale: dark to medium gray snd green-gray (mottled), ahale; platy, moderate induration, spsrsely fossiliferous with shell fragments, small high-spired gastropods, ostracodes, and rare small crinoid columnals (mainly near base of unit), common to sparse horizontal burrows (Chondrites).	6	0	1.83
	W1.5	16. Havensville Shale: green-gray and dark gray (mottled), skeletal, calcirudite (packestone); thinly to shaly bedded, very argillaceous; very fossiliferous with Aviculopecten, small gastropods, bivalve ahell qragments, ostrscodes, productid spines, rand rare small crinoid columnsls. TA	0	5	0.13
	W1.4	15. Havensville Shale: green-gray snd yellowish gray to dark gray (mottled), shale; platy, silty, slightly cslcareous, sparaely fossiliferoua with bivalve shell fragments, Aviculopecten, ostracodes, and sparse to rsre small crinoid columnals.	1	3	0.38
	W1.4	14. Havensville Shale: yellowish gray and green-gray to dark gray (mottled), shale; very calcareoua, platy to fissile, poor to moderate induration; very fossiliferous with common Derbyia, Composita, Neochonetes, Enteletes, fenestrate and ramose bryozoa, crinoids, echinoids, productids (Reticulatia, Linoproductus?), and sparae Straparolus, trilobites, Meekella, and ostracodes, most specimens are large (robust) in form. TA	0	5	0.13
THREEMILE	W1.3	13. Threemile Limestone: light to medium gray, weather's pale yellow-orange, skeletal calcarenite; nonbedded at base with thin irregular beds at top, moderate to well indurated, slightly argillaceous, becoming increasingly more argillaceous at the top; fossils: brachiopod shell fragments, bryozoa fragments, crinoids, echinoids, and ostrscodes, fossila are commonly abraded (sub rounded to occasionally well rounded).	0	11	0.28
THREEMILE	W1.3	12. Threemile Limestone: very light gray to light pale yellow-orange, skeletal, fine cslcarenite to coarse calcilutite (wackestone); thick bedded (massive), moderate to locally poor induration, chalky (powdery on fresh broken surface), very porous with common vugs snd solution pita, common to locally sbundant rosette crystal molds many filled with microcrystalline qusrtz; chert; 8 in. thick bedded chert layer at top of unit, light gray to dark blue-gray, weathers white to light gray; 2 in. thick nodular chert layer 26 in. from base of unit, light to dark gray; 3 in. thick layer of bedded chert 6 in. from base of unit, light to dark gray, weathers white to very light gray; all chert layera fossiliferous ssme as limestone; fosails: abundant fenestrste bryozoa, brschiopod shell fragments, sparse to rare Composita, spsrse Enteletes crinoids, echinoids, productid spines, and ostrscodes.	5	2.5	1.59
THREEMILE	W1.3	11. Threemile Limeatone: light yellowish gray to light pale yellow-orange, skeletal, calcarenite (wackestone); thick bedded, moderate to well indurated, porous with common solution pits, slightly chalky, common to locally abundant rosette crystal molds; chert; dark to very light gray, weathera very light gray to white; one layer of bedded chert at baae 4 in. thick, one lsyer of nodulsr chert 20 in. from base of unit, fosail content of both chert layera same ss limestone; fossils: brachipod shell fragments, fenestrate and ramose bryozod, crinoids, echinoids, sparse Composita, productid spines, and ostracodes.	2	8.5	0.83

Section GY2

THREEMILE	W1.3	10. Threemile Limestone: light to medium gray and dark gray (mottled), skeletal, calcarenite) (wackestone); nonbedded, argillaceous, well indurated, common rosette crystal molds; fossils: brachiopod shell fragments, Composita, Reticulatia, fenestrate and ramose bryozoa, crinoids, productid spines, echinoids, sparse to rare bivalve shell fragments, and ostracodes.	0	4.5	0.11
		9. Threemile Limestone: yellow-gray to dark gray (mottled), shale; very calcareous, platy, moderate to well indurated, sparse to locally common rosette crystal molds; very fossiliferous: Composita, Derbyia, Enteletes, crinoids, fenestrate and ramose bryozoa, echinoids, productid spines, ostracodes, trilobites, and rare sharks teeth. TA	0	7.5	0.19
	W1.2	8. Threemile Limestone: light pale yellow-orange, skeletal, calcarenite; nonbedded, moderate to well indurated, slightly less fossiliferous at the base and top of the unit, slightly coarser grained toward the top with sparse to rare small limestone intraclasts at top of the unit, algal? fragments in upper portion of the unit, occasional rosette and rectangular crystal molds; chert; three layers; one layer of bedded chert, dark gray to very light gray, fossiliferous same as limestone, located 19 in. from base; two layers of nodular chert, dark gray to very light gray, fossiliferous same as limestone, one located 12 in. from base on 2 to 3 in. from top; fossils: brachiopod shell fragments, sparse to rare Composita, bryozoa, crinoids, echinoids, productid spines, and ostracodes.	2	9.5	0.85
		7. Speiser Shale: yellowish gray and medium gray (mottled) shale; calcareous, shaly bedded, moderate to poorly indurated; sparsely fossiliferous with brachiopod shell fragments, small crinoid columnals, echinoids, sparse Enteletes, chonetids, productids, bryozoa fragments, and ostracodes.	0	4	0.10
		6. Speiser Shale: yellowish gray and medium gray (mottled) shale; very calcareous, shaly bedded, moderate induration; very fossiliferous with crinoids, Derbyia, Composita, Neochonetes, productids, fenestrate and ramose bryozoa, echinoids, productid spines, sparse Enteletes, trilobites, and ostracodes, less fossiliferous toward top of unit, most specimens are large (robust) in form. TA	0	8.5	0.22
	W1.1	5. Speiser Shale: yellowish gray and medium gray (mottled) shale; calcareous, shaly bedded, moderate induration; sparsely fossiliferous with Aviculopecten, Orbiculoidea, ostracodes, Straparolus, and sparse to rare small crinoid columnals, and bryozoa fragments.	0	3	0.08
		4. Speiser SHale: yellowish gray and medium gray (mottled), shale; calcareous, shaly bedded, moderate induration; sparsely fossiliferous with Aviculopecten, productid shell gragments, productid spines, and ostracodes.	1	1	0.33
		3. Speiser Shale: medium gray to yellowish gray, weathers yellowish gray, intraclastic, skeletal, coarse calcarenite to calcirudite; thin bedded, moderate to well indurated, common to abundant limestone and shale intraclasts (up to 0.36 in.), becomes slightly finer grained toward top, conglomeratic; fossils: Aviculopecten, small high-spired gastropods, bivalve shell fragments, ostracodes, and sparse brachiopod shell fragments. TA	0	7	0.18

Section GY2

Formation	Unit	Description			
	W1.1	2. Speiser Shale: green-gray, claystone; nonbedded, blocky, occasional granule size grains of calcite; fossiliferous with ostracodes, and sparse to rare shell fragments.	0	7	0.18
FUNSTON		1. Speiser Shale: olive green, shale; nonbedded, blocky, moderate to well indurated, calcareous, occasional to common yellow-green root mottles, unfossiliferous.			

State: KS County: Geary Quadrangle: Swede Creek

Locality Description:

Roadcuts on the north side of Interstate Highway 70, 3.7 to 3.9 miles west of intersection with Interstate Route 77, in the NW¼, SE¼, T. 11 S., R. 7E.

Section GY3

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
SCHROYER	W2.2	38. Schroyer Limestone: light to meduim gray, weathers pale yellow-orange and dark gray, skeletal, calcarenite; massive, well indurated, cherty, occasional rosette and rectangular crystal molds; Chert; 2 zones of bedded chert, 1 in. from base (3.5 in. thick) and 8 in. from base (11 in. thick), dark gray and dark blue-gray to very light gray, commonly mottled in appearance, locally vuggy, upper chert bed contains irregular patches of cherty limestone, fossiliferous same as limestone; Fossils: common *Composita*, *Reticulatia*, bryozoa, sparse crinoids, echinoids, productid spines, *Neochonetes*, *Aviculopecten*, *Aviculopinna*?, and ostracodes; calcarenite: cherty, brachiopod biomicrite (wackestone).	1	9	0.53
		37. Schroyer Limestone: light yellow-gray, weathers pale yellow-orange, shale; shaly bedded, platy, very calcareous, moderate to well indurated; fossiliferous with common *Composita*, *Reticulatia*, bryozoa, sparse crinoids, echinoids, productid spines, *Derbyia*, ostracodes, and rare *Aviculopecten*, and *Aviculopinna*?	0	4	0.10
		36. Schroyer Limestone: light gray, weathers pale yellow-orange, skeletal, coarse calcilutite to calcarenite: nonbedded, blocky, well indurated, cherty, sparse vugs; Chert; 3 zones of chert; 2 layers of nodular chert, 8.5 in. (2 in. thick) and 12.5 in. (2 in. thick) above base, dark gray to light gray and white, nodules commonly dark in center becoming lighter outward, fossiliferous same as limestone; one layer of bedded chert, 17 in. from base (2 to 3 in. thick), dark gray to very light gray, occasionally mottled in appearance, locally vuggy, fossiliferous same as limestone; fossils: common fenestrate and ramose bryozoa, brachiopod shell fragments, sparse *Composita* (common toward top), *Reticulatia*, crinoids, ostracodes, and rare *Aviculopecten*; coarse calcilutite to calcarenite: cherty, brachiopod, bryozoa biomicrite (wackestone).	2	1	0.64
	W2.1	35. Havensville Shale: light yellow-gray to light pale yellow-orange, weathers same, claystone; nonbedded, crumbly, calcareous, poorly indurated, with abundant calcite geodes; unfossiliferous.	2	9	0.84
		34. Havensville Shale: light to medium yellowish gray, weathers pale yellow-orange, skeletal, coarse calcilutite; nonbedded, blocky, moderate to well indurated, common shaly partings, argillaceous, common irregularly shaped vugs, fossils: common *Composita*, *Derbyia*, sparse productid shell fragments, crinoids, echinoids, fenestrate and ramose bryozoa, ostracodes, and rare trilobites; coarse calcilutite: argillaceous, brachiopod, biomicrite (wackstone). TA	0	11	0.28
		33. Havensville Shale: light gray and medium gray (mottled), weathers pale yellow-orange, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, common yellow-orange (Fe-oxide) staining, basal 4 in. consists of interbedded limestone and calcareous shale; shale; shaly bedded, fissil, very calcareous, fossiliferous sames as limestone; fossils: common fenestrate and remoae bryozoa, sparse *Wilkingia*, crinoids, echinoids, bivalve shell fragments, ostracodes and rare trilobites; coarse calcilutite: argillaceous, bryozoan biomicrite (wackestone).			

Section GY3 continued

THREEMILE	W1.7	32. Havensville Shale: light to medium gray, weathers light gray, claystone; nonbedded, blocky, moderate to well indurated, abundant irregularly shaped calcareous nodules (caliche-like), common callapse structures; unfossiliferous.	0	9	0.23
		31. Havensville Shale: light to medium gray, weathers light gray, claystone; shaly bedded, platy, moderate to well indurated, occasional very thin (up to 0.06 in.) lenses of medium gray calcareous material, sparse irregularly shaped calcareous nodules, occasional horizontal burrows; sparsely fossiliferous with Aviculopecten, and rare unidentifiable shell fragments.	1	0	0.30
		30. Havensville Shale: green-gray to yellowish green-gray, weathers light gray, claystone; indistinct bedding, blocky, moderate to well indurated, occasional patches of calcareous material, common lenses of coarse sand-sized material; sparsely fossiliferous with Aviculopecten (found mostly in lower portion of unit).	0	4.5	0.11
		29. Havensville Shale: medium gray to orangish gray, weathers pale yellow-orange, skeletal, coarse calcarenite; thin bedded, slabby, well indurated, argillaceous, sparse to common small (up to 0.24 in.) micritic intraclasts and occasional cobble-size, algal (osagia?) coated intraclasts; intraclasts consist of dark gray, sparsely fossiliferous (bivalves, ostracodes) calcilutite; large intraclasts found mainly at top of unit; fossils: abundant bivalve shell fragments, algae (seen as Osagia-like coatings on shell fragments and intraclasts), and rare forams; coarse calcarenite to calcirudite (locally): argillaceous, intraclasts, ostracode, molluscan biomicrite (wackstone). TA	0	4	0.10
	W1.6	28. Havensville Shale: light green-gray, weathers pale yellow-orange, shale; shaly bedded, platy, calcareous, moderate induration, occasional thin lenses of calcareous material (up to 0.13 in. thick); sparsely fossiliferous with Permophorus, and ostracodes.	0	4	0.10
		27. Havensville Shale: yellowish gray to light and medium gray, weathers pale yellow-orange and dark gray, skeletal, calcilutite to coarse calcilutite; thinly bedded, slabby, argillaceous, well indurated, occasional lenses of coarser material (mainly shell debris), sparse small limestone (sparsely fossiliferous calcilutite) intraclasts (found mainly in middle portion of unit), occasional large vugs, coarser grained (coarse calcilutite) and slightly more fossiliferous in middle portion of the unit; Fossils: basal 4 in. contains common bivalve shell fragments, (Aviculopecten and Permophorus) and algal fragments (blue-green? algae, seen as small clumps of finely laminated micrite and organic rich material); the middle portion (approx. 5 in.) contains common Aviculopecten, Permopherous, brachiopod shell fragments, sparse productid spines, small high-spired gastropods, and ostracodes; top 5 in. contains sparse bivalve shell fragments (permophorus, Aviculopecten) ostracodes, and rare productid spines, some shell fragments are algal (Osagia) coated; calcilutite to coarse calcilutite: argillaceous, intraclast bearing, molluscan biomicrite (wackstone). TA	1	3	0.38
	W1.5	26. Havensville Shale: yellowish gray to yellowish green-gray, weathers pale yellow-orange, claystone; nonbedded, blocky, silty, very poor to moderate induration, sparse medium gray, angular, micritic limestone intraclasts (up to 1.5 in.), found primarily in lower portion of unit; occasional pale yellow-orange calcareous lenses, and occasional calcareous nodules in the upper 3 in.; unfossiliferous.	0	10	0.25

Section GY3 continued

THREEMILE	W1.5	25. Havensville Shale: olive green-gray and dark gray (mottled), weathers green-gray, shale; shaly bedded, slabby, moderate induration, abundant horizontal burrows (Chondrites), occasional thin lenses of calcareous material; sparsely fossiliferous with Aviculopecten, Permophorus, rare Aviculopinna, and ostracodes (commonly found concentrated in thin, up to .12 in., lenses or as part of burrow fillings).	2	8	0.81
		24. Havensville Shale: medium to dark gray, weathers pale orange-gray, calcilutite; very thinly bedded, slabby, argillaceous and silty, well indurated, common horizontal burrows; unit is composed of alternating layers (0.15 to 0.25 in.) of argillaceous limestone and very calcareous shale, containing occasional lenses of coarser material consisting of pellets?, pelloids, shell fragments, and productid spines, these are commonly found between limestone and shale layers containing rare shell fragments and pellets. TA	0	2	0.05
	W1.4	23. Havensville Shale: olive green to green-gray, weathers light green-gray, mudstone; nonbedded, blocky, moderate to well indurated, silty, occasional thin to very thin gray limestone lenses; very sparsely fossiliferous with rare Aviculopecten, with one specimen of a conical cephalopod and an internal mold of a bellerophont also found.	2	1	0.64
		22. Havensville Shale: green gray and dark gray (mottled), weathers medium gray, shale; shaly bedded, platy to slabby, moderate induration, occasional thin to very thin, light to medium gray, micritic, limestone lenses, common horizontal burrows (Chondrites), sparsely fossiliferous with Orbiculoidea, Permophorus, rare Aviculopecten, and internal molds of small high-spired gastropods.	7	1	2.16
		21. Havensville Shale: green-gray and dark gray (mottled), weathers medium gray, shale; shaly bedded, platy, moderate induration, occasional thin lenses of silt-sized to sand-sized material (mainly shell debris), common horizontal burrows (Chondrites); sparsely fossiliferous throughout except two zones, 2 in. from base (2 in. thick) and one at top (3 in. thick), commonly fossiliferous; fossils; Aviculopecten, small crinoid columnals, and ostracodes.	0	10	0.25
		20. Havensville Shale: yellowish gray to green-gray, weathers light to medium gray, shale; shaly bedded, spintery to platy, very calcareous, moderate to well indurated, common limonitic and hematitic staining, common shell hash lenses; very fossiliferous with common to abundant Derbyia, Composita, crinoids fenestrate and ramose bryozoa (including Thamnopora, and Stenopora), Neochonetes, Reticulatia, productid shell fragments and spines, Meekella, echinoid plates and spines, sparse Enteletes, Rhipidomella, Permophorus, Straparolus, Crurythyrus, ostracodes, and rare bellerophonts (Euphemites?), coiled nautiloids, and shark teeth, most specimens are large (robust) in form, and commonly articulated. TA	0	6	0.15
	W1.3	19. Threemile Limestone: light to medium gray, weathers pale yellow-orange, skeletal, fine calcarenite (at base) to coarse calcarenite (at top); indistinct bedding, blocky to slabby at top, slightly silty and argillaceous toward top of unit, well indurated, common lenses of coarse sand-sized shell debris, cherty with occasional fossil fragments (mainly bryozoa) partially replaced by microcrystalline quartz; fossils: abundant fenestrate bryozoa fragments, common brachiopod shell fragments, echinoid plates and spines, sparse crinoids, productid spines, and ostracodes, fossils are mainly fragmented and show signs of abrasion with common sub-rounded to rounded fossil fragments; fine to coarse calcarenite: chert bearing, brachiopod, fenestrate bryozoa biomicrite (wackstone at base, packestone at top).	1	0	0.30

Section GY3 continued

Formation	Unit	Description	ft	in	m
THREEMILE	W1.3	18. Threemile Limestone: very light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, calcarenite; massive, blocky, chalky, moderate to well indurated, unit becomes coarser grained toward the top, porous with common solution pits and vugs, occasional rosette and rectangular crystal molds throughout, 3 in. zone of abundant vugs, rectangular and rosette crystal molds at base of unit; Chert: 2 zones of bedded chert, one at the top (8 in. thick) one 11 in. from top (3 in. thick) of unit, dark gray and dark blue-gray to very light gray, occasionally mottled in appearance, fossiliferous same as limestone, upper chert zone contains irregular patches of cherty limestone, sparse opal fracture-fillings, unit is gypsiferous and contains sparse chert nodules between bedded chert layers; fossils: common to abundant fenestrate bryozoa, common brachiopod shell fragments, sparse <u>Enteletes</u>, crinoids, echinoids, productid spines, ostracodes, and rare <u>Composita</u>, occasional layers of common <u>Enteletes</u>; coarse calcilutite (at base) to calcarenite (at top): cherty, brachiopod, bryozoan biomicrite (wackstone).	3	8	1.12
		17. Threemile Limestone: light yellow-gray, weathers pale yellow-orange, skeletal, coarse calcilutite; massive, blocky, well indurated, cherty, slightly chalky, sparse rosette and rectangular crystal molds throughout, some rosettes filled with white opalline silica, two zones of abundant rosettes and vugs (2 to 4 in. thick) located 4 in. and 20 in. from base, well developed stylolite 4 in. from base; Chert; 4 zones of chert are present; 3 layers of bedded chert, one at base (3 in. thick) of unit; dark gray to dark blue-gray and very light gray, occasionally mottled in appearance, fossiliferous same as limestone; one layer of nodular chert (1 in. thick), 6 in. above base, dark gray to very light gray, fossiliferous same as limestone; upper most chert bed surrounded by abundant rosette and rectangular crystal molds; fossils: fenestrate (common to abundant) and ramose (sparse) bryozoa, common brachiopod shell fragments, sparse crinoids, echinoids, <u>Enteletes</u>, productid spines, ostracodes, and rare <u>Composita</u>; coarse calcilutite: cherty, brachiopod, bryozoa biomicrite (wackstone).	2	2	0.66
		16. Threemile Limestone: light gray to dark gray (mottled), weathers light gray to yellowish gray, skeletal, calcarenite; indistinct bedding, blocky, argillaceous, gradational lower contact, common rosette and rectangular crystal molds; Fossils: <u>Composita</u>, <u>Neochonetes</u>, common to abundant fenestrate and ramose bryozoa fragments, crinoids, echinoid, sparse <u>Enteletes</u>, <u>Reticulatia</u>, productid shell fragments and spines, ostracodes, and rare <u>Derbyia</u>, and trilobites, occasional shell fragments (mainly bryozoa) partially replaced by microcrystalline quarts, matrix is slightly recrystallized micrite with occasional pellets; calcarenite: argillaceous, chert bearing, brachiopod, bryozoan biomicrite (wackestone).	0	3.5	0.09
		15. Threemile Limestone: yellow-gray, green-gray and dark gray (mottled), weathers pale green-gray, shale; shaly bedded, splintery to platy, very argillaceous, moderate to well indurated, common rosette and rectangular crystal molds, occasionally filled with white opalline silica; very fossiliferous with <u>Composita</u>, <u>Derbyia</u>, fenestrate and ramose bryozoa, productid shell fragments (<u>Reticulatia</u>, <u>Linoproductus</u>), <u>Neochonetes</u>, crinoids, echinoids, sparse <u>Enteletes</u>, <u>Straparolus</u>, <u>Wellerella</u>, <u>Ditomopyge</u>, ostracodes (including <u>Amphissites</u> and <u>Bairdia</u>), rare <u>Orbiculoidea</u>, and sharks teeth, most specimens are large (robust) and commonly articulated. TA	0	9	0.23
	W1.2				

Section GY3 continued

THREEMILE	W1.2	14. Threemile Limestone: light to medium gray, weathers pale yellow-orange, skeletal, calcilutite (at base) to calcarenite (middle and top); massive, blocky, well indurated, cherty, coarser grained in middle and upper portion of unit, abundant rosette and rectangular crystal molds in lower 5 in., slightly argillaceous at base and top of unit, sparse small micritic limestone intraclasts in upper 2 in., matrix is slightly recrystallized micrite with occasional pellets visable, pellets are also found filling some articulated brachiopod (Wellerella) shells; Chert; two zones; one layer bedded chert (5 in. thick), 13 in. from base; dark gray and dark blue-gray to very light gray and white, commonly darker in center and lighter toward edges, occasional opal fracture-fillings, fossiliferous same as limestone; one layer nodular chert (2 in. thick), 22 in. from base, description same as bedded chert; fossils: common brachiopod shell fragments, fenestrate and ramose bryozoa, sparse Composita (absent in upper 3 to 4 in., rare in basal 5 in.), crinoids, echinoids, productid spines, ostracodes, rare algal fragments in the upper 3 to 4 in., with a 3 in. zone of abundant Wellerella, 9 in. from base of unit, occasional fossil fragments (mainly bryozoa) partially replaced by microcrystalline and/or chalcedonic quartz, middle portion of unit more fossiliferous than base or top; calcilutite to calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).	2	2	0.66
		13. Speiser Shale: light green-gray and dark gray (mottled), shale: shaly bedded, fissile to platy, calcareous, moderate induration; sparsely fossiliferous with sparse small crinoid columnals, bryozoa fragments, productid shell fragments and spines, Enteletes, small chonetids, calcareous worm tubes (Spirorbis), ostracodes (including Amphassites, and Hollinella), rare Rhipidomella, Petrocrania?, smaller forams (including Tetrataxis, and Polytaxis), trilobite fragments, and rare vertebrate remains (fish teeth), fossils are found mainly concentrated at base of unit.	0	4	0.10
		12. Speiser Shale: greenish gray, yellowish gray, and dark gray (mottled), weather pale green-gray, shale; shaly bedded, platy to fissile, calcareous, sparse irregular masses of crystalline calcite (secondary in origin); fossiliferous with Derbyia, (locally abundant in concentrated lenses), Neochonetes, Reticulatia, productid fragments and spines, fenestrate and ramose bryozoa, sparse crinoids, echinoid plates and spines, ostracodes (including Bairdia, and Hollinella), Composita (sparse to rare and very small in size), and rare trilobites (Ditomopyge), Petrocrania, smaller forams, phophatic shell fragments, and vertebrate remains (fish teeth).	0	7	0.18
		11. Speiser Shale: green-gray, yellowish gray, gray, and dark gray (mottled), weathers pale green-gray, shale; shaly bedded, platy to blocky, very calcareous, common argillaceous shell hash lenses, sparse irregular masses crystalline calcite (secondary in origin), forms a slightly resistant ledge in outcrop; very fossiliferous with abundant Derbyia, crinoids, common Composita, Neochonetes, Reticulatia, productid shell fragments and spines, echinoid plates and spines, fenestrate and ramose bryozoa, ostracodes (including Amphissites, Hollinella, and Bairdia), sparse Aviculopecten, rare Straparolus, Orbiculoidea, Ditomopyge, internal molds of small planispiral and trochospiral gastropods, smaller forams, and vertebrate remains (fish teeth), most specimens are large (robust) in form, and commonly articulated. TA	0	6	0.15

Section GY3 continued

THREEMILE	W1.1	10. Speiser Shale: light green-gray and dark gray, weathers green-gray, shale; shaly bedded, splintery to platy, silty, poor to moderate induration, calcareous; sparsely fossiliferous with *Aviculopecten*, *Orbiculoidea*, *Straparolus*, productid shell fragments and spines, ramose bryozoa fragments, ostracodes (including *Hollinella*, *Bairdia*, and *Amphissites*), echinoids, and rare small crinoids, *Permophorus*, smaller forams (including *Tetrataxis*, and *Globivalvulina*), and fragmentary vertebrate remains (fish teeth).	0	3	0.08
		9. Speiser Shale: light green-gray and dark gray (mottled), weathers green-gray, shale; shaly bedded, splintery to platy, silty, calcareous, poor to moderate induration, sparse irregular masses of crystalline calcite (secondary in origin); fossiliferous with *Aviculopecten*, productid shell fragments and spines, ostracodes (including *Bairdia*, *Hollinella*, *Amphissites*, and *Cavellina*), sparse bryozoa fragments, echinoids, smaller forams (including *Textrataxis*, and *Globivalvulina*), and rare small crinoid columnals, and fragmentary vertebrate remains (fish teeth).	1	6	0.46
		8. Speiser Shale: medium and light gray (mottled), weathers light yellowish gray, skeletal, fine calcarenite; indistinct (thin) bedding, slabby to blocky, argillaceous, well indurated, locally vuggy, common black (Mn-oxide?) and yellow-orange (Fe-oxide) staining, sparse to rare mudstone intraclasts (up to 0.08 in.); fossils: abundant to common small high-spired gastropods, *Aviculopecten*, ostracodes, sparse productid spines, brachiopod shell fragments, fenestrate bryozoa fragments, bivalve shell fragments, algae (Osagid grains and Osagia-like coatings on fossil fratments), and rare echinoid fragments, smaller forams, and fragmentary vertebrate remains (fish teeth and bones); fine calcarenite: argillaceous, intraclast bearing, molluscan, ostracode biomicrite (wackestone). TA	0	8.5	0.22
		7. Speiser Shale: olive green, weathers pale greenish gray, claystone; nonbedded, blocky, calcareous, moderate induration, common yellow-orange Fe-oxide staining; fossiliferous with sparse ostracodes, productid spines, rare shell fragments, and smaller forams (*Tetrataxis*, and *Globivalvulina*).	1	0	0.30
FUNSTON		6. Speiser Shale: greenish gray to pale red (mottled), claystone; nonbedded, blocky, calcareous, moderate induration, silty and slighty sandy, granule- to pebble-sized calcareous nodules, common dark gray to pale red root traces and mottles, root traces occasionally lined with green shale; unfossiliferous.	1	1	0.33
		5. Speiser Shale: olive green, weathers pale green, claystone; nonbedded, blocky, moderate induration, common microslickensides, with sparse possible root(?) traces; unfossiliferous.	0	5	0.13
		4. Speiser Shale: variegated (pale red, gray, tan, yellowish green-gray, green-gray), claystone; nonbedded, blocky, silty, moderate induration, occasional granule- to pebble-sized calcareous (caliche-like) nodules, with common root traces; unfossiliferous.	0	5	0.13
		3. Speiser Shale: same as unit 5.	0	4	0.10
		2. Speiser Shale: gray to pale red, weathers green-gray, claystone; nonbedded, blocky, slightly calcareous, moderate induration, occasional microslickensides, with common dark gray root traces; unfossiliferous.	0	9	0.23

Section GY3 continued

FUNSTON

1. Speiser Shale: dark red-brown, weathers light to medium red-gray, silty claystone to siltstone; nonbedded, blocky, moderate to well indurated; occasional pale green-gray, lenses of same; abundant root traces and occasional microslickensides; unfossiliferous.

Thin-section data was used to suppliment descriptions of the following units: 8, 14, 16, 17, 18, 19, 24, 27, 29, and 33.

Sieve analysis data was used to suppliment descriptions of the following units: 6, 7, 9, 10, 11, 12, and 13.

State KS County Riley Quadrangle Randolph

Locality Description

Core from the Amoco Production Company #1 Hargrave, NE¼, NE¼, NE¼ NE¼, sec. 32, T. 7 S., R. 6 E., description is from the 340.0 foot mark up to the 298.2 foot mark.

Section RY1

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ; – – – Climate Change Surface)	Unit Thicknesses ft	in	m
SCHROYER	W2.1	39. Havensville Shale: medium to dark gray, mudstone; nonbedded, blocky, well indurated, slightly calcareous (slight effervescence), with abundant white and medium gray patches or "blebs" of gypsum (average diameter 3/4 in.) and common thin selenite lenses.	1	6	0.46
		38. Havensville Shale: medium gray, mudstone; nonbedded, blocky, well indurated, calcareous, occasional small blebs of gypsum, with rare unidentifiable shell fragments.	0	9	0.23
		37. Havensville Shale: light to medium gray, skeletal calcarenite; interlaminated (alternating light and medium gray), argillaceous, moderate to well indurated, common vugs, occasional lenses of fossil debris, occasional patches or blebs (up to 0.5 in.) of gypsum in the upper portion of the unit with a 3/4 in. thick layer of selenite 1 in. from the base of the unit; fossils: crinoids, bivalve shell fragments, sparse brachiopod shell fragments, ostracodes, and rare bryozoa.	1	5	0.43
		36. Havensville Shale: variegated yellowish gray, green-gray, light gray, and dark gray, calcilutite; nonbedded, argillaceous, blocky, well indurated, mottled in appearance, occasional thin shale partings; appears bioturbated; several stylolites present; with a 2.5 in. thick zone, 4 in. from the base, containing common small gypsum crystal; calcilutite: argillaceous, gypsiferous micrite (mudstone).	1	6	0.46
		35. Havensville Shale: light gray, with abundant medium to dark gray laminations, calcilutite; laminated, argillaceous, possibly carbonaceous, well indurated, darker laminations argillaceous and possibly carbonaceous, stylolite present 12.75 in. from base of unit, with occasional lenses of coarse crystalline calcite found 8 in. above base of unit; calcilutite: argillaceous micrite.	1	10	0.56
THREEMILE	W1.7	34. Havensville Shale: medium to dark gray, claystone; laminated, platy, calcareous, modurate induration, lower 4 feet lighter in color and more calcareous than upper portion, occasional thin (0.15 in.) elenite lenses throughout unit, 4 ft. 3.5 in above the base of the unit is a 5 in. zone of abundant irregular to round masses of white gypsum and clear selenite lenses, above this gypsiferous zone the unit contains occasional, light gray, laminations of calcareous material; no fossils found.	7	8	2.34
		33. Havensville Shale: light to medium gray, calcilutite; nonbedded, blocky, well indurated, argillaceous with sparse dark gray to dark reddish gray lenses of argillaceous material; no fossils found.	0	8.5	0.22
		32. Havensville Shale: light to medium gray, skeletal, calcilutite; nonbedded, blocky, well indurated, argillaceous with common dark gray to dark reddish gray lenses of argillaceous material, bioturbated; fossils: ostracodes and sparse shell fragments; calcilutite: argillaceous, biomicrite (fossiliferous mudstone).	0	7	0.18

Section RY1 continued

THREEMILE	W1.6	31. Havensville Shale: dark gray with common light gray lenses or laminae, shale; laminated, platy to flaggy, calcareous, becoming more calcareous toward the top, silty, moderate induration; no fossils found	0	9	0.23
		30. Havensville Shale: light to medium gray, skeletal, coarse calcilutite; nonbedded, blocky, moderate to well indurated, very argillaceous with common dark gray to dark red-gray lenses of argillaceous material, bioturbated; fossiliferous with bivalve shell fragments, productid spines, and ostracodes; coarse calcilutite: argillaceous, bivalve biomicrite (wackestone). TA	1	8	0.51
	W1.5	29. Havensville Shale: dark gray, shale; thinly laminated, platy to fissile, poor to moderate induration, slightly calcareous, occasional lenses of selenite (up to 0.5 in. thick), with common horizontal burrows (<u>Chondrites</u>?), and possible plant macerals; no fossils found.	2	8	0.81
		28. Havensville Shale: medium gray, skeletal, calcirudite; shaly bedded, very argillaceous, with common lenses or laminations of dark gray argillaceous material; very fossiliferous with abundant bivalve shells (<u>Aviculopecten</u>), and sparse small crinoid columnals, and bryozoa fragments; calcirudite: argillaceous, <u>Aviculopecten</u> biomicrite (packestone). TA	0	1	0.03
	W1.4	27. Havensville Shale: dark gray, shale; laminated, platy, calcareous, moderate induration; sparsely fossiliferous with bivalve shell fragments, small crinoid columnals, and ostracodes.	0	3	0.08
		26. Havensville Shale: light gray and dark gray (mottled), shale: shaly bedded, with interbedded calcareous and argillaceous material, silty, moderate to well indurated; very fossiliferous with crinoids, brachiopod shell fragments, bryozoa, echinoids, productid spines, and ostracodes, unit becomes less fossiliferous toward the top. TA	0	7.5	0.19
	W1.3	25. Threemile Limestone: light gray and dark gray, skeletal, calcarenite to calcirudite; thinly bedded with interbedded calcareous (light gray) and argillaceous (dark gray) material slabby, very argillaceous, moderate to well indurated; upper 5 in. contains large fossiliferous limestone rip-up clasts, medium to light gray, rounded, with brachiopod crinoid, bryozoa, echinoid, and ostracode shell fragments; fossils: common brachiopod shell fragments, crinoids, bryozoa, and sparse echinoids, productid spines, and ostracodes, fossils are mostly fragmented; Calcarenite to Calcirudite: argillaceous, intraclast, brachiopod, biomicrite (wackestone to packestone).	0	10	0.25
		24. Threemile Limestone: light to medium gray, skeletal, calcarenite; nonbedded, blocky, well indurated, slightly argillaceous at base to argillaceous at top, occasional small (up to 1 in.), medium gray, cherty limestone nodules; fossils: fenestrate and ramose bryozoa, brachiopod shell fragments, sparse crinoids, echinoids, productid spines, and ostracodes; calcarenite: cherty, argillaceous, bryozoa, brachiopod biomicrite (wackestone).	3	1.5	0.98

Section RY1 continued

THREEMILE	W1.3	23. Threemile Limestone: light gray and medium gray (locally mottled in appearance), skeletal, calcarenite; nonbedded, blocky, well indurated, porous with occasional vugs throughout, chalky, occasional dark reddish gray irregular patches and rosettes of gypsum throughout, lower 6 in. contains abundant gypsum patches and rosettes, thin (0.25 to 0.5 in.) layer of gypsum 19 in. from base, surrounded by numerous rosettes and patches of gypsum; Chert: two zones; one layer of nodular chert, 19 in. from the base, medium gray, fossiliferous same as limestone; 6 in. layer of bedded chert at top of unit, dark gray to black at base, light to medium gray (mottled) in upper portion, occasional irregular patches of cherty limestone, fossiliferous same as limestone; fossils: fenestrate bryozoa, brachiopod shell fragments, sparse crinoids, echinoids, productid spines, and ostracodes; calcarenite: cherty, gypsiferous, bryozoan, brachiopod, biomicrite (wackestone).	3	1.5	0.98
		22. Threemile Limestone: light to medium gray, skeletal, calcarenite; nonbedded, blocky, well indurated, cherty, with sparse small patches (rosettes) of red-gray gypsum in the upper 1 in. to 2 in.; Chert: one zone, 4 in. thick, of nodular chert at the top of the unit, dark gray to light gray (darker in centers of nodules grading to light gray on borders), fossiliferous same as limestone; fossils: brachiopod shell fragments, fenestrate bryozoa, sparse crinoids, echinoids, productid spines, and ostracodes; calcarenite: cherty, gypsiferous, bryozoan, brachiopod biomicrite (wackestone).	0	10.5	0.27
		21. Threemile Limestone: medium gray to black, shale; very calcareous, shaly bedded, platy, well indurated; fossiliferous with crinoids, brachiopod shell fragments, sparse bryozoa, echinoids, and productid spines.	0	2	0.05
		20. Threemile Limestone: medium gray with occasional very thin dark gray lenses, skeletal, coarse calcarenite; nonbedded, blocky, well indurated, very argillaceous; fossiliferous with brachiopod shell fragments, crinoids, bryozoa, sparse echinoids, ostrocodes, and productid spines, coarse calcarenite: argillaceous, crinoidal, brachiopod biomicrite (wackestone).	0	5.5	0.14
		19. Threemile Limestone: medium gray and dark gray (mottled), shale; very calcareous, indistinct bedding, splintery, silty, well indurated; very fossiliferous with brachiopod shell fragments, crinoids, bryozoa, sparse echinoids, productid spines, ostracodes, and rare coral (horn-like). TA	0	7	0.18
	W1.2	18. Threemile Limestone: light gray to dark gray in lower 5 in., light to medium gray in upper portion, skeletal, calcarenite; nonbedded, blocky, well indurated, argillaceous in upper 2 in., and lower 4 in., cherty; Chert; 3 in. to 4 in. thick layer of irregularly bedded chert, 3 in. from top of unit, light gray to medium gray, irregular (nodular) upper and lower boundaries, fossiliferous same as limestone; fossils: brachiopod shell fragments, crinoids, bryozoa, echinoids, productid spines, and ostracodes; calcarenite: cherty, argillaceous, brachiopod biomicrite (wackestone).	1	1.5	0.34
		17. Speiser Shale: medium gray to dark gray (mottled), shale; shaly bedded, silty, well indurated, very calcareous in lower 8 in., to calcareous in upper 6 in., finer grained in upper 6 in.; very fossiliferous at base to sparsely fossiliferous at top, with abundant brachiopod shell fragments, common crinoids, fenestrate and ramose bryozoa, echinoids, productid spines, and sparse ostracodes, many of the specimens large (robust) in form. TA	1	2	0.36

Section RY1 continued

Formation	Unit	Description	ft	in	m
THREEMILE	W1.1	16. Speiser Shale: green-gray, shale; shaly bedded, platy to flaggy, moderate to well indurated, calcareous, silty to sandy; sparsely fossiliferous with bivalve shell fragments, ostracodes, and sparse to rare brachiopod shell fragments, upper 2 in. contains sparse small crinoid columnals.	0	5	0.13
		15. Speiser Shale: green-gray, shale; shaly bedded, platy to flaggy, moderate to well indurated, calcareous, silty to sandy; fossiliferous with bivalve shell fragments (<u>Aviculopecten?</u>), ostracodes, and brachiopod shell fragments, becomes less fossiliferous toward top of unit.	0	8	0.20
		14. Speiser Shale: medium gray to green-gray (with wisps of dark gray), skeletal, calcarenite; nonbedded, blocky, well indurated, argillaceous, common small (average 0.04 in.) micritic limestone and shale intraclasts; unit is considered a coarse calcarenite in the lower 1 in. fining upward to a calcarenite in the middle and coarsens again in the top 1 in. to a calcirudite; fossils: common ostracodes, bivalve shell fragments and in the upper 1 in., sparse brachiopod shell fragments. TA	0	6	0.15
		13. Speiser Shale: light to medium gray (with occasional dark gray wisps), claystone; indistinct bedding with shaly bedding apparent locally, silty, calcareous, bioturbated, common dark gray mottling toward top of unit; occasional thin lenses of gypsum; fossiliferous with sparse ostracodes, and rare shell fragments.	0	9	0.23
FUNSTON		12. Speiser Shale: green-gray, claystone; nonbedded, blocky, moderate induration, silty, slightly calcareous, occasional thin lenses of gypsum; unfossiliferous; with occasional reddish gray root mottles.	2	7	0.79
		11. Speiser Shale: red-gray and green-gray, claystone; nonbedded, moderate induration, silty, locally sandy; unfossiliferous; with fine (root?) mottles.	0	2.5	0.06
		10. Speiser Shale: light green-gray, claystone; nonbedded, blocky, silty, moderate induration; unfossiliferous; with common medium gray mottles.	0	4.5	0.11
		9. Speiser Shale: same as unit 11.	0	3.5	0.09
		8. Speiser Shale: green-gray, claystone; nonbedded, blocky, silty, calcareous, moderate induration, occasional dark red-gray (root?) mottles; unfossiliferous.			
		7. Speiser Shale: red-gray, claystone; nonbedded, blocky, calcareous, poor to moderate induration, appears laminated locally; unfossiliferous.	1	6	0.46
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		6. Speiser Shale: light green-gray, claystone; nonbedded, blocky, moderate to well indurated, calcareous; unfossiliferous; with occasional root mottles in the lower 4 in., and abundant root mottles in the upper 7 inches	0	11	0.28
		5. Speiser Shale: medium red-gray, claystone; nonbedded, blocky, silty, moderate induration, noncalcareous; unfossiliferous; with sparse root mottles.	0	3.5	0.09
		4. Speiser Shale: green-gray, claystone; nonbedded, blocky, silty, moderate induration, calcareous; unfossiliferous; with sparse root mottles.	0	9.5	0.24
		3. Speiser Shale: medium dark green-gray, claystone; nonbedded, blocky, silty, moderate induration, calcareous, occasional lenses (0.04 in. thick) of gypsum; sparsely fossiliferous with ostracodes.	1	1	0.33

Section RY1continued

FUNSTON		2. Speiser Shale: medium gray, calcilutite; nonbedded, blocky, well indurated, common fenestral like vugs filled with crystalline calcite and or gypsum, occasional gypsum lenses at the top of the unit; unfossiliferous; with possible root mottles.	0	10.5	0.27
		1. Speiser Shale: medium to dark red-gray, claystone; nonbedded blocky, silty, moderate to well indurated; unfossiliferous; with common root mottles and traces.	1	1	0.33

State: KS County: Riley Quadrangle: Olsburg SW

Locality Description:

Outcrop along the western side of Tuttle Creek Lake, SW¼, SW¼, Sec., 7, T. 8 S., R. 7 E.

Section RY2

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – – Climate Change Surface	Unit Thicknesses ft	in	m
THREEMILE	W1.3	14. Threemile Limestone: very light gray to light yellowish gray, weathers orangish gray, skeletal, coarse calcilutite; nonbedded, blocky, porous, moderate to well indurated, chalky, occasional rosette crystal molds; Chert; 3 in. thick layer of bedded chert, 16 in. from base; dark gray and dark blue-gray to white, occasionally mottled in appearance, fossiliferous same as limestone; fossils: common fenestrate bryozoa, sparse crinoids, brachiopod shell fragments, productid spines, sparse to rare <u>Composita</u>, <u>Enteletes</u>, echinoid fragments, and ostracodes; coarse calcilutite: cherty, brachiopod, (fenestrate) bryozoan biomicrite (wackestone).	2	3	0.69
		13. Threemile Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, slightly argillaceous at base, thin shaly parting at top of unit, occasional rosette crystal molds; fossils: fenestrate and sparse ramose bryozoa, brachiopod shell fragments, productid shell fragments and spines, crinoids, sparse <u>Composita</u>, echinoid plates and spines, ostracodes, and sparse to rare <u>Enteletes</u>; coarse calcilutite: brachiopod, bryozoan biomicrite (wackestone).	0	6	0.15
		12. Threemile Limestone: yellowish green-gray, yellowish gray, medium gray (mottled), weathers yellowish gray, shale; shaly bedded, splintery, moderate to well indurated, very calcareous; upper 3 in. more calcareous and better indurated than lower portion; very fossiliferous with <u>Derbyia</u>, <u>Composita</u>, <u>Reticulatia</u>, chonetids, crinoids, echinoid plates and spines, sparse <u>Meekella</u>, <u>Enteletes</u>(?), productid spines, ostracodes, rare trilobites, and rare sharks teeth, most specimens are large (robust) in form, and commonly articulated. TA	0	8	0.20
	W1.2	11. Threemile Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, fine calcarenite; nonbedded, blocky, well indurated, basal and upper 1 to 2 in. of unit is argillaceous; Chert; one layer of bedded chert (approximately 5 in. thick) 2 inches from top of unit; dark gray and dark blue-gray to light gray and white, commonly mottled in appearance, common patches of cherty limestone, fossiliferous same as limestone; Fossils: fenestrate and ramose bryozoa fragments, brachiopod shell fragments, productid spines, sparse echinoid plates and spines, ostracodes, and rare <u>Composita</u>; fine calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).	1	0	0.30
		10. Speiser Shale: light gray to light yellowish gray, shale; indistinct bedding, platy to blocky, moderate induration; sparsely fossiliferous with small brachiopod shell fragments, small crinoid columnals, sparse to rare small ramose bryozoa fragments, and ostracodes.	0	1.5	0.04

Section RY2 continued

THREEMILE	W1.2	9. Speiser Shale: green, green-gray, and yellowish green-gray (mottled), weathers light green-gray, shale; shaly bedded, platy, modurate induration, calcareous; fossiliferous with crinoids, fenestrate and ramose bryozoa, sparse to locally common Derbyia, chonetids, productids (Reticulatia), echinoids, ostracodes, sparse to rare Aviculopecten, and rare trilobite fragments, less fossiliferous toward top.	0	8	0.20
		8. Speiser Shale: green, green-gray, and yellowish green-gray (mottled), weathers light green-gray, shale; shaly bedded, splintery, very calcareous with occasional shell hash lenses, moderate to well indurated, forms slightly resistent ledge in outcrop; very fossiliferous with crinoids, Derbyia, Composita, Reticulatia, chonetids (Neochonetes), fenestrate and ramose bryozoa, echinoid plates and spines, sparse Aviculopecten, Orbiculoidea shell fragments, Ditomopyge, and ostracodes, most specimens are large (robust) and commonly articulated. TA	0	5	0.13
	W1.1	7. Speiser Shale: green-gray, yellowish green-gray, and green (mottled), weathers light green-gray, shale; shaly bedded, platy, moderate induration, common yellow-orange staining; fossiliferous with common Orbiculoidea shell fragments, Aviculopecten, productid shell fragments and spines, sparse Straparolus, ostracodes, and rare ramose bryozoa fragments.	0	2	0.05
		6. Speiser Shale: shale same as unit 7; fossiliferous with common Aviculopecten, productid shell fragments and spines, ostracodes, and rare ramose bryozoa fragments.	1	0	0.30
		5. Speiser Shale: medium gray, weathers orangish gray, coarse calcarenite; nonbedded, blocky, well indurated; common sand-sized to pebble-sized limestone intraclasts. 0.15 in. zone at base of unit contains abundant intraclasts, occasional large horizontal burrows; fosailiferous with bivalve shell fragments, Aviculopecten, Aviculopinna(?), ostracodes, rare productid spines, and rare echinoid(?) fragments; coarse calcarenite: intraclast, molluscan biomicrite (wackestone). TA	0	8.5	0.22
		4. Speiser Shale: green-gray, weathers same, claystone; nonbedded, blocky to granular, moderate induration, occasional coarse sand-sized calcareous nodules; sparsely fossiliferous with ostracodes.	0	2	0.05
FUNSTON		3. Speiser Shale: variegated (yellowish-orange, light gray, yellowish green, and green-gray), claystone; nonbedded, blocky, moderate to poor induration, silty, occasional granule to pebble-sized calcareous nodules, occasional root mottles; no fossils found.	0	3	0.08
		2. Speiser Shale; green-gray, claystone; nonbedded, blocky, moderate to poor induration, silty, pale yellow-orange to white mottles, common root mottles; no fossila found.	1	4	0.41
		1. Speiser Shale; light greenish gray, claystone; nonbedded, blocky, poor induration, silty, calcareous, abundant green-gray and yellowish orange root mottles; unfossiliferous			

State: KS County: Riley Quadrangle: Keats

Locality Description:

Roadcut along north side of Highway 77, just west of junction with Highway 113 (approximately 2 miles north of Manhattan, Kansas), SE¼, SE¼, Sec. 23, T. 9 S., R. 7 E.

Section RY3

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	ft	in	m
THREEMILE	W1.3	16. Threemile Limestone: very light yellowish gray to white, weathers pale yellow-orange, skeletal coarse calcilutite (wackestone); massive, blocky, moderate to well indurated, porous, chalky, common rosette and rectangular crystal molds, 1 in. thick shaly parting at base of unit; Chert; three zones, two layers at bedded chert, one 7 in. (4 in. thick) from base, one at top (9 in. thick); dark gray and dark blue-gray to white, occasionally mottled, upper shert bed contains occasional patches of cherty limestone, fossiliferous same as limestone; one layer nodular chert (2 in. thick) dark gray centers grading outward to white borders, fossiliferous same as limestone; fossils: common to abundant fenestrate bryozoa, common brachiopod shell fragments, productid spines, sparse Composita, Enteletes, crinoids, echinoids, and ostracodes.	3	7	1.09
		15. Threemile Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, coarse calcilutite to calcarenite (wackestone); massive, blocky, well indurated, common rosette crystal molds (abundant at top of unit), slightly argillaceous at base; Chert; 4 in. thick layer bedded chert, 8 in. from base; dark gray to white, occasionally mottled, fossiliferous same as limestone; fossils: fenestrate and sparse ramose bryozoa, brachiopod shell fragments, Composita, Enteletes, productid shell fragments (Reticulatia?) and spines, crinoids, echinoids, and ostracodes, becomes less fossiliferous toward top.	1	8	0.51
		14. Threemile Limestone: medium greenish gray, yellowish gray, and yellow-orange (mottled), weathers light greenish gray, shale; shaly bedded, platy to splintery, very calcareous with occasional shell hash lenses; very fossiliferous with Derbyia, Composita, crinoids, productids (Reticulatia, Linoproductus?). Neochonetes, fenestrate and ramose bryozoa, echinoid plates and spines, productid spines, sparse Enteletes, ostracodes, Ditomopyge, and ostracodes, most specimens are large (robust) in form, and commonly articulated. TA	0	8	0.20
	W1.2	13. Threemile Limestone: light gray, weathers pale yellow-orange, skeletal, fine calcarenite; nonbedded, blocky, well indurated, argillaceous in upper 1.5 in., sparse to rare small limestone intraclasts in upper 2 in. of unit; Chert; 5 in. thick layer of bedded chert 8 in. from base; dark gray and dark blue-gray to very light gray, commonly mottled in appearance, occasionaly patches of cherty limestone, fossiliferous same as limestone; fossils: fenestrate and sparse ramose bryozoa, brachiopod shell fragments, sparse Composita, crinoids, echinoids, and ostracodes, slightly more fossiliferous in middle portion of unit, with only articulated specimens being found in central portion of unit.	1	3	0.38

Section RY3 continued

THREEMILE	W1.2	12. Speiser Shale: medium greenish gray to yellow-orange (mottled), weathers light greenish gray shale; shaly bedded, splintery, very calcareous (in lower 8 in.) to calcareous, occasional shell hash lenses in lower 8 in., moderate to locally well indurated (in lower 8 in.): very fossiliferous with Derbyia, Composita, Reticulatia, crinoids, fenestrate and ramose bryozoa, Neochonetes, echinoid plates and spines, sparse Straparolus, Aviculopecten, Orbiculoidea shell fragments, ostracodes. and Ditomopyge, upper 3 in. of unit very sparsely fossiliferous with brachiopod shell fragments, productid spines, small ramose bryozoa fragments, and ostracodes. TA	1	2	0.36
THREEMILE	W1.1	11. Speiser Shale: greenish gray to yellow-orange (mottled), weathers light greenish gray, shale; shaly bedded, splintery to platy, calcareous, moderate induration; sparsely fossiliferous with Aviculopecten, Orbiculoidea, sparse productid shell fragments, and spines, sparse to rare small crinoid columnals, Straparolus, and ostracodes.	0	2	0.05
		10. Speiser Shale: greenish gray to yellow-orange (mottled), weathers light greenish gray, shale; shaly bedded, platy to spintery, calcareous, moderate induration; fossiliferous with Aviculopecten, sparse productid shell fragments and spines, rare Pinna(?) ostracodes, and rare small crinoid columnals.	0	10	0.25
		9. Speiser Shale: light yellowish gray, weathers pale yellow-orange, skeletal, fine calcarenite (wackestone); nonbedded, blocky, well indurated, slightly argillaceous at base; fossils: abundant ostracodes, common bivalve shell fragments, Aviculopecten, Pinna(?) sparse to rare productid spines, and rare echinoid(?) fragments. TA	1	0	0.30
		8. Speiser Shale: interbedded limestone and shale; light to medium gray, skeletal (ostracodes) calcilutite; and green-gray and pale yellow-orange (mottled) shale containing abundant ostracodes; common horizontal burrows throughout.	0	6	
FUNSTON		7. Speiser Shale: green to yellowish green, weathers gray-green, silty claystone: nonbedded granular, occasional microslickensides; no fossils found.	0	5	0.13
		6. Speiser Shale: light gray to buff, silty claystone; nonbedded, blocky, moderate induration, common yellow-orange staining, microslickensides, with abundant greenish gray root mottles; unfossiliferous.	0	10	0.25
		5. Speiser Shale: green to green-gray, weathers same, silty claystone; nonbedded, granular, moderate induration; unfossiliferous.	0	3	0.08
	?				
		4. Speiser Shale: light greenish gray, weathers same, silty claystone; nonbedded, blocky, common yellow-orange, staining, occasional microslickensides, calcareous, with common medium to dark green and reddish gray root mottles; unfossiliferous.	1	0	0.30
		3. Speiser Shale: medium reddish gray, weathers some, silty claystone; nonbedded, blocky, calcareous, with common dark red-gray root mottles; unfossiliferous.	0	5	0.13
		2. Speiser Shale: light greenish gray, medium gray, and red (mottled), silty claystone; nonbedded, blocky, moderate induration, calcareous, with abundant medium green root mottles; unfossiliferous.	0	5	0.13

Section RY3 continued

FUNSTON

1. Speiser Shale: dark red-brown, weathers red-gray, silty claystone; nonbedded, blocky, moderate to well indurated, with common root mottles and traces; unfossiliferous.

State: KS	County: Riley
Quadrangle	Manhattan

Locality Description.

Roadcuts on the east side of highway 113, 1.3 to 1.4 miles north of intersection with Kimbell Street (Manhattan, Kansas), at approximately C, N½, Sec. 2, T. 10 S., R. 7 E.

Section RY4

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
SCHROYER	W2.2	14. Schroyer Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, fine calcarenite to coarse calcilutite (wackestone); nonbedded, blocky, well indurated, porous with common small vugs, common small dark specks throughout unit, Chert; 3 layers bedded chert, 18 in. from base (4 in. thick), 25 in. from base (8 in. thick), and one at top (5 in. thick); dark gray to dark blue-gray and light gray to white, occasional patches of cherty limestone, sparse opal fracture-fillings, fossiliferous same as limestone; fossils: fenestrate and sparse ramose bryozoa, sparse _Composita_, chonetids, productids (_Reticulatia?_), productid spines, crinoids, echinoids, ostracodes, and rare _Aviculopecten_.	2	3	0.69
		13. Schroyer Limestone: light pale yellow-orange, weathers pale yellow-orange, skeletal, fine calcarenite to coarse calcilutite; nonbedded, blocky, moderate induration, chalky (powdery on fresh broken surface), porous with common small vugs, common small dark specks throughout; fossils: common to locally abundant fenestrate and sparse ramose bryozoa, sparse _Composita_, chonetids(?), productids (_Reticulatia?_), productid spines, crinoids, echinoids, ostracodes, and rare _Aviculopecten_.	1	6	0.46
		12. Schroyer Limestone: light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, fine calcarenite: nonbedded, blocky, well indurated; Chert; two zones; 3.5 in. thick layer of bedded chert, 4 in. from base; dark gray to dark blue-gray and very light gray to white, commonly darker in center grading outward to lighter colors, fossiliferous same as surrounding limestone; layer of nodular chert (2 in. thick) at top of unit; same description as above; fossils: fenestrate and sparse ramose bryozoa, sparse _Composita_, chonetids, _Reticulatia_, productid fragments and spines, crinoids, echinoids, and ostracodes.	0	11	0.56
	W2.1	11. Havensville Shale: greenish gray, weathers light greenish gray, claystone; nonbedded, crumbly texture, calcareous, common calcite geodes and calcareous nodules; unfossiliferous.	1	10	.56
		10. Havensville Shale: light yellowish gray in lower 4 in., yellowish gray, medium gray, and dark gray (mottled) in upper 4 in., skeletal, fine calcarenite; nonbedded, blocky, well indurated, abundant rectangular crystal molds, upper 4 in. cherty with occasional fossil fragments partially replaced by microcrystalline quartz, common irregular masses of crystalline calcite (up to 1.0 in.); fossils: brachiopod shell fragments, fenestrate and ramose bryozoa, sparse crinoids, echinoids, productid spines, and ostracodes.	0	8	0.2
		9. Havensville Shale: pale yellow-orange, weathers same, skeletal, coarse calcilutite; nonbedded to thinly bedded in upper 5 in., blocky to slabby, moderate to well indurated, common rectangular crystal molds, abundant calcite geodes (up to 3.0 in.) in a zone 3 in. from base; fossils: common productid fragments and spines, sparse echinoid plates and spines, fenestrate and ramose bryozoa, ostracodes, rare _Composita_, _Lingula_, and crinoids; coarse calcilutite: brachiopod biomicrite (wackestone).	1	1.5	0.3

Section RY4 continued

THREEMILE	W1.7	8. Havensville Shale: greenish gray, weathers light greenish gray, shale; shaly bedded, blocky, moderate to well indurated, slightly calcareous, sparse plant fragments; sparsely fossiliferous with Lingula, sparse to locally common on some bedding planes.	1	5	0.43
		7. Havensville Shale: light pale yellow-orange, weathers same, calcilutite; very thinly bedded, slabby, poor to moderate induration, powdery texture, occasional vuggy porosity; sparsely fossiliferous with sparse to rare bivalve and ostracode shell fragments. TA	0	2	0.05
	W1.6	6. Havensville Shale: green-gray, weathers light greenish gray, siltstone; nonbedded, blocky, moderate induration, common thin (up to 0.25 in.) lenses of white to light yellowish gray, powdery, calcareous material; sparsely fossiliferous with ostracodes.	1	0	0.30
		5. Havensville Shale: light green-gray, weathers same, siltstone; nonbedded, blocky, moderate induration, occasional thin (up to 0.25 in.) lenses of white to light yellowish gray, powdery, calcareous material; sparsely fossiliferous with sparse to locally common ostracodes.	0	7	0.18
		4. Havensville Shale: yellowish gray, medium gray in top 1 in., weathers pale yellow-orange, skeletal, calcirudite; very thinly bedded, slabby, moderate induration, common medium to dark gray shale intraclasts (many flat in shape and oriented subparallel to bedding), upper 0.5 in. is almost solely composed of intraclasts with a few bivalve shell fragments; fossils: abundant Permophorus, common bivalve shell fragments, ostracodes, sparse productid spines, Aviculopecten, echinoid? fragments, and unidentifiable shell fragments; calcirudite: shale intraclasts, ostracode, bivalve (Permophorus) biomicrite (wackestone to packstone). TA	0	4	0.10
		3. Havensville Shale: yellowish orange to light yellowish gray (mottled), weathers same, skeletal, calcilutite; thinly bedded, flaggy, moderate to well indurated, occasional large (up to 1 in.) vugs, chalky (powdery on fresh broken serface), sparse horizontal burrows; fossils: sparse Permophorus, bivalve shell fragments, productid spines, ostracodes, and rare Aviculopecten; calcilutite: bivalve biomicrite (wackestone).	1	1	0.33
		2. Havensville Shale: yellowish gray to pale yellow-orange, weathers same, skeletal, coarse calcilutite; thin bedded, blocky, chalky, moderate to well indurated, common brown to brown-gray staining (usually associated with shell fragments); fossils: common Aviculopecten, bivalve shell fragments, sparse Permophorus, productid spines, ostracodes, and unidentifiable shell fragments, elongate fossil fragments randomly oriented in a micritic matrix; coarse calcilutite: bivalve biomicrite (wackestone).	0	4	0.10
	W1.5	1. Havensville Shale: yellowish olive green to light greenish gray (mottled), weathers greenish gray, claystone; nonbedded, blocky, silty, moderate induration, slightly calcareous, sparse vuggy porosity, occasional horizontal burrows; sparsely fossiliferous with Aviculopecten and unidentifiable shell fragments.	1	4	0.41

State: KS County: Riley Quadrangle: Manhattan

Locality Description:

Roadcuts on the west side of highway 113,* 1.2 miles north of intersection with Kimbell Street (Manhattan, Kansas), approximately at c, sec. 2, T. 10 S., R., 7 E.

Section RY5

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.6	6. Havensville Shale: yellowish gray to pale yellow-orange, weathers same, skeletal, coarse calcilutite; thin bedded, blocky, chalky, moderate to well indurated, common brown to brown-gray staining (usually associated with shell fragments); fossils: common Aviculopecten, bivalve shell fragments, sparse Permophorus, productid spines, ostracodes, and unidentifiable shell fragments, elongate fossil fragments randomly oriented in a micritic matrix; coarse calcilutite: bivalve biomicrite (wackestone). TA	0	4	0.10
	W1.5	5. Havensville Shale: yellowish olive green to light greenish gray (mottled), weathers greenish gray, claystone; nonbedded, blocky, silty, moderate induration, slightly calcareous, sparse vuggy porosity, occasional horizontal burrows; sparsely fossiliferous with Aviculopecten and unidentifiable shell fragments.	1	4	0.41
		4. Havensville Shale: olive green and dark gray (mottled), weathers greenish gray, shale; indistinct bedding, platy, moderate induration, slightly calcareous, occasional horizontal burrows (Chondrites); sparsely fossiliferous with sparse Permophorus, Orbiculoidea, rare Aviculopecten, ostracodes, unidentifiable shell fragments, and in the lower 3 ft. rare bryozoa fragments, occasional lenses (up to 3 in. thick) of concentrated fossil debris.	6	3	1.91
		3. Havensville Shale: medium to dark gray (locally mottled in appearance), weathers pale yellow-orange and gray, skeletal, calcirudite; very thin to thinly bedded, slabby, argillaceous, well indurated; very fossiliferous with abundant Aviculopecten, common small gastropods, sparse brachiopod shell fragments, echinoid fragments, bryozoa, productid spines, rare crinoids, ostracodes, and bellerophontacians; calcirudite: argillaceous, molluscan (Aviculopecten) biomicrite (packestone). TA	0	7	0.18
	W1.4	2. Havensville Shale: dark gray and olive green (mottled), weathers medium to dark gray, shale; indistinct bedding, platy, moderate induration, common horizontal burrows (Chondrites), many are filled with pellets (average diameter 0.02 in.); very sparsely fossiliferous with rare Avicolopecten, ostracodes, and small unidentifiable shell fragments.	2	0	0.61
		1. Havensville Shale: yellowish olive green to yellowish gray, weathers yellowish orange to yellowish gray, shale; shaly bedded, splintery, very calcareous with occasional shell hash lenses, moderate to well indurated, common to locally abundant vertical and horizontal burrows 0.17 in. to 0.40 in. in width; very fossiliferoun with abundant Derbyia, common Composita, Neochonetes, productids (Reticulatia, Linoproductus?), Enteletes, fenestrate and ramose bryozoa, crinoids, echinoids, productid spines, ostracodes, sparse Meekella, Ditomopyge, Straparolus, and rare shark teeth, most specimens are large (robust) in form, and commonly articulated. TA			

Section RY5 continued

Thin section data was used to suppliment descriptions of the following units: 3.

Sieve analysis data was used to suppliment descriptions of the following units: 2, and 4.

State. KS County Riley Quadrangle Manhattan

Locality Description:
Roadcut on the east side of Highway 112, 1.1 to 1.2 miles north of intersection with Kimbell Street, Manhattan, Kansas, approximately at C., sec. 2., T. 10 S., R. 7 E.

Section RY6

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.3	15. Threemile Limestone: variegated (light yellowish gray, yellow-orange, greenish gray, gray), mottled in appearance weathers gray to orangish gray, skeletal, fine calcarenite; indistinct bedding, blocky to flaggy, well indurated, slightly chalky, porous with common solution pits and vugs, occasional rectangular crystal molds, cherty with occasional fossil fragments (mainly bryozoa) partially replaced by microcrystalline and chalcedonic quartz, argillaceous in upper portion of unit; fossils: common fenestrate bryozoa, sparse brachiopod shell fragments, productid spines, ostracodes, and echinoid plates and spines, fossils are all fragmented; fine calcarenite: argillaceous, brachiopod bearing, fenestrate bryozoan biomicrite (wackestone).	0	11	0.28
		14. Threemile Limestone: pale yellow-orange, weathers same, skeletal, calcarenite; massive in appearance thick laminations apparent on fresh broken surface, flaggy, well indurated, common yellow-orange staining, common elongate (horizontally) solution pits, occasional rectangular crystal molds; fossils: abundant fenestrate bryozoa fragments with common large fenestrate bryozoa fronds on bedding surfaces, sparse brachiopod shell fragments, ostracodes, echinoid plates and spines, productid spines, rare crinoids, and bivalve shell fragments, occasional fossil fragments (mainly bryozoa) partially replaced by microcrystalline quartz; calcarenite: cherty, brachiopod bearing, fenestrate bryozoan biomicrite (wackestone).	0	7	0.18
		13. Threemile Limestone: white to light gray, weathers pale yellow-orange, skeletal, calcarenite; massive, blocky, chalky, porous with occasional solution pits and vugs throughout, occasional rosette and rectangular crystal molds throughout, unit becomes slightly coarser grained toward top, cherty with occasional fossil fragments partially replaced milky white chert; chert; 4 zones of chert, 3 nodular chert layers, 15 in. (2 in. thick), 27 in. (3 in. thick), and 31 in. (2 in. thick) from the base of the unit; dark gray to dark blue-gray and light gray to white, commonly darker in centers grading outward to lighter colors, occasionally mottled in appearance, fossiliferous same as limestone; one layer bedded chert (3 in. thick), at top of unit, description as above; fossils: abundant fenestrate and sparse to rare ramose bryozoa, sparse _Composita_, _Enteletes_, brachiopod shell fragments, productid spines, crinoids, echinoids, and ostracodes; calcarenite. cherty, brachiopod, fenestrate bryozoan biomicrite (wackestone).	3	1	0.94
		12. Threemile Limestone: light gray to light yellowish gray, weathers pale yellow-orange, skeletal, calcarenite; massive blocky, well indurated, common rosette and rectangular crystal molds, 2 in. thick zone of abundant rosettes 10 in. from base, cherty; chert; 2 zones of chert; 5 in. thick layer nodular chert 2 in. from base, dark gray and dark bluish gray to light gray and white, darker in center, lighter on edges of nodules, fossiliferous same as limestone; 4 in. thick layer bedded chert at top of unit; dark gray to very light gray and white, commonly mottled in appearance, fossiliferous same as limestone; fossils: common fenestrate and ramose bryozoa, sparse _Composita_, _Enteletes_, crinoids, echinoids, ostracodes, productid shell fragments and spines, and rare trilobite fragments;	1	8.5	0.52

Section RY6 continued

THREEMILE	W1.3	calcarenite: cherty, bryozoan, brachiopod briomicrite (wackeatone).			
		11. Threemile Limestone: light gray, yellowish gray, and dark gray (mottled), weathers pale yellow-orange, shale; shaly bedded, platy to splintery, very calcareous, moderate induration, upper 5 in. more calcareous (than lower portion) and well indurated; very fossiliferous with common Derbyia, Composita, Neochonetes, crinoids, productid shell fragments (Reticulatia)and spines, sparae Enteletes, fenestrste and ramose bryozoa, echinoids, ostracodes, rare Ditomopyge, Straparolua, and shark teeth, most specimens are large (robust) in form, and commonly articulated. TA	1	0	0.30
	W1.2	10. Threemile Limestone: light gray to light yellowiah gray, weathers pale yellow-orange, skeletal, calcsrenite; massive, blocky, well indurated, cherty, upper 1 inch is argillaceous and contains sparse to rare, small (up to 0.13 in.) limeatone intraclaats, less fossiliferous snd finer grained in the lcwer 3 to 5 in. and upper 1 in. of the unit; chert; 4 in. thick layer of bedded chert 10 in. from base; dark gray and dark bluish gray to very light gray or white, commonly mottled in appearance, fossiliferous same as limestone; fossila: common fenestrate and ramoae bryozoa, sparse Composita (rare at base, abaent in upper portion of unit), crinoids, echinoids, brachiopod ahell fragments, productid spines, and oatracodea; calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).	1	4	0.41
		9. Speiser Shale: variegated (green-gray, yellowish gray, light to dark gray), mottled in sppearance, weathers green-gray, shale; ahsly bedded, splintery, calcareous, moderate induration; sparaely fossiliferous with sparse brachiopod shell fragments, productid fragments snd spines, echinoids, ostracodes, and rare chonetids.	0	4	0.10
		8. Speiser Shale: variegsted (same as unit 9), weathers greenish gray, shale: shaly bedded, splintery to platy, very calcareous with common limestone and/or shell hash lenaes, moderste to well indurated, forms slightly resistant ledge in outcrop; very fossiliferous with common Derbyis, Neochonetes, productid shell frsgments snd spines, Reticulatia, fenestrate and ramose bryozoa, ostracodes, abundant crinoids, sparse echinoid plstes snd spinea, Composita, Aviculopecten, rsre Strspsrolua, Orbiculoidea shell fragments, trilobite fragments, and fragmentsry vertebrste remains (shark teeth, fish teeth snd bones), most apecimens sre large (robust) in form snd are commonly articulated. TA	0	7	0.18
	W1.1	7. Speiser Shale: variegated (same as unit 9), mottled, weathers light to medium greenish gray, shale; indistinct bedding, splintery to platy, calcareous, moderste induration; foaailiferous with common Orbiculoidea, oatracodes, sparse Aviculopecten, productid shell fragments and spines, bryozoa fragments and Straparolus.	0	5	0.13
		6. Speiser Shale: variegated (as in unit 9), mottled, weathers light to medium greenish gray, shale; shsly bedded, splintery to platy, calcareous, moderste indurstion foasiliferous with productid shell fragmenta and spines, ostracodes, sparse Aviculopecten, bryozoa frsgments, Straparolus, and rsre echinoid plates and spines.	0	11	0.28
		5. Speiser Shale: light to medium gray and yellowiah gray (mottled), weathers pale yellow-orange, akeletsl,	1	4	0.41

Section RY6 continued

THREEMILE	W1.1	calcarenite; thinly bedded at base, medium bedded at top, flaggy to slabby, well indurated, common vugs locally, lower portion of unit consists of alternating layera of coarse (medium calcarenite) and find (coarse calcilutite) material, aparse to locally common small (up to 0.13 in.) micritic limestone intraclasts; foasils: common bivalve shell fragments, ostracodes, aparse <u>Aviculopecten</u>, amall gastropods, productid spines, rare bryozoa fragments and echinoid fragments; medium calcarenite: intraclast bearing, ostracode, molluscan biomicrite (wackestone to packestone). TA			
		4. Speiser Shale: light greenish gray with common yellow-orange staining, claystone; thick indiatinct laminations, platy, moderate to poor induration; fossiliferous with abundant ostracodes, found mainly along bedding planes and in thin (up to 0.4 in.) concentrated lenses.	0	9.5	0.24
FUNSTON		3. Speiser Shale: greenish gray, weathers light greenish gray, claystone; nonbedded, blocky, ailty, calcareous, moderate to well indurated, common yellow-orange and rust-red ataining, common light yellow-orange and reddish green calcareous nodules (average diameter 1.5 - 2.0 in.) in upper 10 in. of unit, with abundant root traces and mottles; unfossiliferous.	1	8.5	0.52
		2. Speiser Shale: reddish green, weathers reddish gray, claystone; nonbedded, granular to blocky, silty, moderate induration, abundant yellow-orange mottles; unfossiliferous	0	5	0.13
		1. Speiser Shale: green-gray, weathers light greenish gray, claystone; nonbedded, blocky, silty, alightly calcareous, moderate to well indurated, with aparse root mottles; unfossiliferous.			
		Thin-section data was used to supplement descriptions of the following units: 5, 10, 14, and 15.			

State KS County Riley Quadrangle Manhattan

Locality Description

Roadcuts along the east side of state Highway 13, approximately 2.2 miles South of Manhattan, Kansas, C, N½, Sec. 33, T. 10 S., R. 8 E.

Section RY7

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— / – – – Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.5	18. Havensville Shale: dark gray and olive green (mottled), weathers light greenish gray, shale; shaly bedded, platy, moderate induration, occasional horizontal burrows; very sparsely fossiliferous with rare bivalve shell fragments and molds (Permophorus?)			
		17. Havensville Shale: medium and dark gray, locally mottled, skeletal, medium calcirudite; thinly to very thinly bedded, slabby, moderate to well indurated, argillaceous with occasional thin shaly partings; fossiliferous with abundant Aviculopecten, sparse small gastropods, ostracodes, and rare bryozoa fragments; medium calcirudite: argillaceous Aviculopecten biomicrite (packstone to wackestone). TA	0	8	0.20
	W1.4	16. Havensville Shale: yellowish green-gray and yellow-orange (mottled), shale; shaly bedded (bedding less apparent in lower 5 in.), platy to blocky (at the base) moderate induration; sparsely fossiliferous with bivalve shell fragments, Aviculopecten, and ostracodes.	0	11	0.28
		15. Havensville Shale: yellowish green-gray, gray, and pale yellow-orange (mottled), shale; shaly bedded, platy to splintery, very calcareous, with occasional thin shell hash lenses; fossiliferous with Derbyia, Composita, productids (Reticulatia, Linoproductus), chonetids, fenestrate and ramose bryozoa, large crinoid columnals, echinoid plates and spines, productid spines, ostracodes, rare trilobite fragments, and fragmentary vertebrate remains (sharks teeth, fish teeth and bones). TA	0	5	0.13
	W1.3	14. Threemile Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, coarse calcilutite to calcarenite; indistinct bedding, slabby to blocky, argillaceous in upper portion of unit, silty, cherty; fossils: fenestrate bryozoa fragments, sparse brachiopod shell fragments, ostracodes, rare echinoid fragments and rare productid spines; coarse calcilutite to calcarenite: argillaceous, silty, brachiopod bearing, bryozoan biomicrite (wackestone).	1	0	0.30
		13. Threemile Limestone: very light yellowish gray to white, weathers pale yellow-orange, skeletal, coarse calcilutite to fine calcarenite; thick bedded, to massive, blocky, moderate to well indurated, chalky, porous, occasional to common rosette and rectangular crystal molds; Chert; two layers bedded chert, one 3 in. (2 in. thick) from base, one at top of unit (10 in. thick); dark gray and dark blue-gray to white, commonly mottled in appearance, upper bedded chert layer contains occasional patches of cherty limestone and sparse opal fracture-fillings, lower 4 to 5 in. of upper chert layer is nodular, fossiliferous same as limestone; fossils: fenestrate bryozoa, brachiopod shell fragments, sparse Composita, crinoids, echinoids, productid spines, sparse to locally common (on some bedding planes) Enteletes, and crinoids; unit is slightly coarser grained toward top; coarse calcilutite to fine calcarenite (at top): cherty brachiopod, bryozoan biomicrite (wackestone).	4	0	1.2

Section RY7 continued

Formation	Unit	Description	ft	in	m
THREEMILE	W1.3	12. Threemile Limestone: light pale yellow-orange, weathers grayish orange, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, sparse to locally common rosette and rectangular crystal molds, 1 in. thick zone of common vugs, rosette and rectangular crystal molds at top of unit; Chert; 4 in. thick layer of bedded chert (5 in. from base); dark gray and dark blue-gray to white, occasionally mottled, fossiliferous same as limestone; occasional small (1 in. diameter) cherty limestone nodules at base of unit; basal 1 to 2 in. of unit is argillaceous; fossils: fenestrate and sparse ramose bryozoa fragments, brachiopod shell fragments, sparse Composita, crinoids, echinoids, productid shell fragments, and spines, ostracodes, and rare Entelctes(?); coarse calcilutite: cherty, bryozoan, brachiopod biomicrite (Wackestone).	1	6	0.46
		11. Threemile Limestone: yellowish green-gray, yellowish gray, and medium gray (mottled), shale; shaly bedded, splintery to platy, very calcareous with occasional argillaceous limestone and shell hash lenses, moderate to well indurated; very fossiliferous with Derbyia, Composita, chonetids, Reticulatia, Linoproductus(?), crinoids, fenestrate and ramose bryozoa, echinoids, productid spines, ostracodes, rare trilobites, and rare sharks teeth, most specimen large (robust) in form, and commonly articulated. TA	0	8	0.20
	W1.2	10. Threemile Limestone: light yellowish gray, weathers pale yellow-orange, skeletal, fine calcarenite; nonbedded, blocky, well indurated; basal 3 in. finer grained (medium calcilutite), slightly argillaceous, less fossiliferous, and contains common rectangular crystal molds; Chert; two zones; layer of nodular chert (2 in. thick), 8 in. from base; dark gray and dark blue-gray centers grading outward to very light gray and white, occasionally mottled in appearance, fossiliferous same as limestone; 4 in. thick layer bedded chert 17 in. from base; description as above, with occasional nodules extending 2 to 3 in. below bedded chert; fossils: bryozoa fragments, brachiopod shell fragments, sparse Composita, crinoids, echinoids, productid spines, and ostracodes; medium calcilutite (at base) to fine calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).	1	11	0.58
		9. Speiser Shale: light greenish gray and medium gray (mottled), weathers same, shale; shaly bedded, splintery to platy, calcareous, moderate induration; fossiliferous to sparsely fossiliferous (at top) with brachiopod shell fragments, small crinoid columnals, Derbyia (found mainly in lower portion of unit), sparse Enteletes (found mainly in upper portion of unit), and ostracodes.	0	10	0.25
		8. Speiser Shale: light green-gray, medium gray, and yellowish gray (mottled), weathers light greenish gray, shale; shaly bedded, splintery to platy, very calcareous with occasional shell hash lenses, moderate to well indurated, forms slightly resistent ledge in outcrop; very fossiliferous with abundant large crinoids, Derbyia, productids (Reticulatia), chonetids (Neochonetes), fenestrate and ramose bryozoa, echinoids, sparse Composita, productid spines, ostracodes, rare trilobites Orbiculoidea fragments and rare fragmentary vertebrate remains (shark and fish teeth), unit becomes less fossiliferous toward top, most specimens large (robust) in form, and commonly articulated. TA			
	W1.1	7. Speiser Shale: light green-gray, medium gray, and yellowish gray (mottled), weathers light greenish gray, shale; shaly bedded, platy, calcareous, moderate induration; fossiliferous to sparsely fossiliferous (at top) with productid shell fragments and spines, sparse Aviculopecten, ostracodes, rare small crinoid columnals, and in upper 2 to 3 in. sparse Orbiculoidea.	1	0	0.30

Section RY7 continued

THREEMILE	W1.1	6. Speiser Shale: light gray to very pale orange, weathers pale yellow-orange, skeletal, calcarenite; nonbedded (upper 11 in.) to very thinly bedded in lower 4 in., slabby to blocky, well indurated, argillaceous in baaal 5 in. with occasional shaly partings; sparse to rare small (sand to granule-size) limestone intraclaats; foaails: bivalve shell fragments, ostracodes, Aviculopecten, productid spinea, and rare echinoid fragments; calcarenite: argillaceous, intraclast bearing, oatracode, molluscan biomicrite (wackestone). TA	1	3	0.38
		5. Speiser Shale: light olive green-gray with darker yellowish green mottles, weathera light greenish gray, claystone: nonbedded, granular texture, slightly calcareous, moderate induration, ailty, occasional granule-size calcareous nodules; fossiliferous with ostracodes.	0	7	0.18
FUNSTON		4. Speiaer Shale: light yellowish green, weathers light greenish gray, claystone; nonbedded, granular texture, moderate to poorly indurated, occasional patches of yellow-green and light olive-brown calcareoua clay, also contains calcareous nodulea; no fossila found.	0	7	0.18
		3. Speiser Shale: dark greenish gray, weathers very light greenish gray, siltstone; nonbedded, granular to blocky, moderate induration, abundant yellowish gray to light browniah gray calcareoua nodulea in upper 1 in. of unit; unfossiliferous.	0	8	0.20
		2. Speiser Shale: light greenish gray, weathers aame, claystone; indistinct thin wavy laminations, blocky, very calcareous, common yellow-orange ataining, well indurated, with sparse to common root traces; unfosailiferous.	0	5	0.13
		1. Speiser Shale: light yellowish green and dark reddish brown (mottled), weathers reddish gray, siltstone; nonbedded, blocky, moderate to well indurated, abundant dark red-gray root mottles; unfoaailiferous.			
		Thin-section data was used to aupplimert descriptions of the following units: 10, 12, and 14.			

State: KS County: Riley Quadrangle: Manhattan

Locality Description:

Roadcuts on the west side of state Highway 13, approximately 2.3 miles south of Manhattan, Kansas, C, N ½, sec. 33, T. 10 S., R. 8 E.

Section RY8

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ; – – – Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.7	8. Havensville Shale: medium gray, weathers pale yellow-orange, skeletal, calcarenite to calcirudite; thin bedded, slabby, well indurated, occasional to common large limestone intraclasts (0.5 in. thick and up to 3.5 in. long), some are algal (Osagia?) coated ; fossiliferous with bivalve shell fragments, and abundant small gastropods; calcarenite to calcirudite: intraclast bearing, molluscan biomicrite (wackestone).	0	5	0.13
		7. Havensville Shale: medium to light gray, weathers pale yellow-orange, skeletal, calcarenite; thinly bedded, slabby, well indurated, lower 4 in. interbedded with thin (0.25 to 1.0 in. thick) lenses of green-gray, fossiliferous (same as limestone), shale; fossils: bivalve shell fragments, Permophorus(?), small gastropods, and sparse ostracodes; unit also contains occasional limestone intraclasts in upper portion; calcarenite: argillaceous, intraclast bearing, molluscan biomicrite (wackestone).	0	10	0.25
		6. Havensville Shale: light gray to light yellowish gray, weathers pale yellow-orange, skeletal, calcirudite; thin bedded, slabby, moderate to well indurated, occasional elongate limestone intraclasts (alligned subparallel to bedding; basal 1.5 in. interbedded with calcareous shale; fossils: common to locally abundant Aviculopecten, small gastropods, bivalve shell fragments, and sparse ostracodes; calcirudite: intraclast bearing molluscan biomicrite (wackestone to packstone). TA	1	3	0.38
	W1.6	5. Havensville Shale: olive, weathers light green-gray, shale; thin to medium laminations, platy to blocky, moderate induration, occasional thin lenses of greenish white powdery calcareous material (upper 0.5 in. is composed of this calcareous material), common horizontal burrows (Chondrites?); occasional thin (up to 0.5 in.) limestone lenses with desiccation (?) cracks; sparsely fossiliferous with sparse to rare Aviculopecten, and Permophorus, fossils occasionally found concentrated in thin lenses.	1	9	0.53
		4. Havensville Shale: olive, medium and dark gray (mottled), weathers light green-gray, shale; shaly bedded, platy to blocky, moderate induration, common horizontal burrows (Chondrites?), occasional thin (up to 0.5 in.) limestone lenses; fossiliferous with Aviculopecten, Permophorus, and sparse to rare ostracodes.	2	0	0.61
		3. Havensville Shale: interbedded limestone and shale; shale; same as unit 4; limestone; light gray calcilutite, very thinly bedded, well indurated, sparsely fossiliferous with bivalve shell fragments (Permophorus?, Aviculopecten?) and ostracodes. TA	0	2	0.05
	W1.5	2. Havensville Shale: dark gray and olive green (mottled), weathers light green-gray, shale; indistinct bedding, platy, moderate induration, occasional horizontal burrows; very sparsely fossiliferous with bivalve shell fragments, and Permophorus.	7	5	2.26

Section RY8 continued

THREEMILE	W1.5	1. Havensville Shale: medium and dark gray (mottled), skeletal, medium calcirudite; thinly to very thinly bedded, slabby, moderate to well indurated, argillaceous with occasional thin shaly partings; fossiliferous with abundant Aviculopecten, sparse small gastropods, ostracodes, and rare small bryozoa fragments; medium calcirudite: argillaceous, *Aviculopecten* biomicrite (packstone to wackestone). TA	0	8	0.20

State: KS County: Riley Quadrangle: Swede Creek

Locality Description.

Roadcuts on the east side of Interstate Route 13, 2.1 to 2.3 miles north of intersection with Interstate Route 70, in the NW¼, NW¼, sec. 21, T. 11 S., R. 8 E.

Section RY9

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ---Climate Change Surface)	ft	in	m
SCHROYER	W2.1	10. Havensville Shale: green-gray with dark gray mottles, weathers pale yellow-orange to gray, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, cherty, occasional quartz geodes; fossils: brachiopod shell fragments, Composita, fenestrate and ramose bryozoa, crinoids, echinoids, productid spines, ostracodes, and sparse bivalve shell fragments; coarse calcilutite: cherty, brachiopod biomicrite (wackstone). TA	1	1	0.33
THREEMILE	W1.7	9. Havensville Shale: green-gray to light yellow-gray, siltstone; nonbedded, blocky to locally puddy-like in texture, sandy, poor to moderate induration, common calcareous (caliche-like) nodules (up to 4 in.); unfossiliferous.	0	11.5	0.29
		8. Havensville Shale: green-gray, shale; indistinct bedding, blocky to platy, calcareous, modurate induration, common small (up to 0.75 in.), light green-gray to gray, calcareous nodules; no fossils found.	0	10	0.25
		7. Havensville Shale: medium gray, skeletal, calcilutite; single bed, blocky, well indurated, silty and slightly argillaceous; fossils: sparse ostracodes, and rare bivalve shell fragments found in a silty micrite matrix. TA	0	2.5	0.06
	W1.6	6. Havensville Shale: yellowish green-gray, shale; shaly bedded, platy, silty, moderate to poor induration, common thin (up to 1 inch) medium gray limestone lenses; very sparsely fossiliferous with rare ostracodes and shell fragments.	0	6	0.15
		5. Havensville Shale: medium gray, skeletal, calcilutite; thinly bedded to laminated, upper portion contains alternating layers (0.5 in. thick) of coarse (more fossiliferous) material with finer, less fossiliferous material, small vertical burrows cut across bedding planes, well indurated; fossils: bivalve shell fragments (locally common), and ostracodes; calcilutite: bivalve biomicrite (wackestone to fossiliferous mudstone). TA	0	5.5	0.14
		4. Havensville Shale: yellowish green-gray, shale; shaly bedded, platy, silty, moderate to poor induration, calcareous, common thin (up to 0.25 in.) medium gray, micritic limestone lenses (more prevelent toward top of unit); very sparsely fossiliferous with rare ostracode shell fragments.	0	8.5	0.22
	W1.5	3. Havensville Shale: yellowish green-gray, claystone; nonbedded, blocky with puddy like texture locally; unfossiliferous.	0	2.5	0.06

Section RY9

THREEMILE	W1.5	2. Havensville Shale: olive green to green-gray and dark gray (mottled), weathers medium gray to green-gray, shale; indistinct bedding, blocky to platy, moderate induration, occasional horizontal burrows; very sparsely fossiliferous with Permophorus and bivalve shell fragments.	8	2	2.49
		1. Havensville Shale: gray and dark gray (mottled), weathers yellow-orange to dark gray, skeletal, calcirudite; thinly to shaly bedded, platy to flaggy, moderate to well indurated, argillaceous with common shale partings, lower 6 in. contains interbedded layers of green-gray to dark gray (mottled) shale; fossils: abundant Aviculopecten, common small gastropods, sparse to rare bellerophants, ostracodes, and small bryozoa fragments; calcirudite: argillaceous, Aviculopecten biomicrite (packestone), TA	1	8	0.51

Thin-section data was used to suppliment descriptions of the following units: 5, and 7.

State KS County: Riley Quadrangle: Swede Creek

Locality Description: Road and stream cuts on the east side of Interstate Route 13, 1.3 miles north of intersection with Interstate Route 70, at SW¼, NW¼, sec. 21, T. 11 S., R. 8 E.

Section RY10

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	Unit Thicknesses ft	in	m
THREEMILE	W1.5	21. Havensville Shale: olive green to green-gray and dark gray (mottled), weathers medium gray to green-gray, shale; indistinct bedding, blocky to platy, moderate induration, occasional horizontal burrows (Chondrites); very sparsely fossiliferous with Permophorus, and bivalve shell fragments.	4	0	1.22
		20. Havensville Shale: gray and dark gray (mottled), weathers yellow-orange to dark gray, skeletal, calcirudite; thinly to shaly bedded, platy to flaggy, moderate to well indurated, argillaceous with common shale partings, lower 6 in. contains interbedded layers of green-gray and dark gray (mottled) shale; fossils: abundant Aviculopecten, common small gastropods, sparse to rare bellerophants, ostracodes and small bryozoa fragments; calcirudite: argillaceous, Aviculopecten biomicrite (packestone). TA	1	8	0.51
	W1.4	19. Havensville Shale: green-gray to dark gray (mottled), shale; shaly bedded, splintery to platy, silty, moderate induration; sparsely fossiliferous with Aviculopecten, bivalve shell fragments, and small crinoid columnals.	0	2.5	0.06
		18. Havensville Shale: greenish gray to dark gray (mottled), shale; shaly bedded, splintery to platy, very calcareous with occasional shell hash lenses; very fossiliferous with Derbyia, Composita, Neochonetes, fenestrate and ramose bryozoa, Reticulatia, crinoids, echinoids, productid spines, ostracodes, and rare trilobites, most specimens large (robust) in form. TA	0	4	0.10
	W1.3	17. Threemile Limestone: light to medium gray, weathers pale yellow-orange, skeletal, calcarenite; thinly bedded, blocky to slabbly, well indurated, cherty, argillaceous in upper portion of unit, becomes coarser grained toward to of unit; fossils: fenestrate bryozoa fragments, brachiopod shell fragments, echinoid plates and spines, crinoids, productid spines, and ostracodes, fossils are mostly fragmented and show signs of abrasion (subrounded), some fossil fragments (mostly bryozoa) are partially replaced by chalcedonic and microcrystalline quartz, productid spines and ostracodes become rare in the upper portion of the unit; calcarenite: argillaceous, chert bearing, bryozoan, brachiopod biomicrite (wackestone to packestone).	1	2	0.36
		16. Threemile Limestone: white to very light gray with occasional yellow-orange staining, weathers pale yellow-orange, skeletal, calcarenite; massive, blocky, moderate to well indurated, chalky, porous with common vugs and solution pits, common rosette crystal molds throughout, rosettes locally abundant in 2 to 4 in. layers 6 in., 23 in., and 40 in. above the base of the unit; chert; 4 zones; one 3 in. layer of nodular chert, 10 in. from base; dark gray to light gray, rare rosette "ghosts" seen in some nodules, fossiliderous same as limestone; 3 layers of bedded chert, 30 in. (3 in. thick), 52 in. (3 in. thick), and 59 in. (7 in. thick) from base of unit, dark gray to light gray and white, occasional patches cherty limestone, fossiliferous	5	5.5	1.66

Section RY10 continued

THREEMILE	W1.3		same as limestone; fossils: brachiopod shell fragments, Enteletes, Composita, fenestrate bryozoa, crinoids, rproductid spines, echinoids, and ostracodes; calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).			
		15.	Threemile Limestone: light gray with dark gray mottles, skeletal, calcarenite; nonbedded, blocky, well indurated, cherty, argillaceous in lower 5 in., slightly argillaceous in upper 7 in., common rectangular and rosette crystal molds throughout some filled with microcrystalline quartz; chert; 2 zones of bedded chert, each 2 to 3 in. thick, one 5 in. from base, one at top of unit: light gray and white to dark blue-gray, fossiliferous same as limestone; fossils: crinoids, bryozoa, Composita, brachipod shell fragments, echinoid plates and spines, productid spines, and ostracodes: calcarenite: argillaceous, cherty, brachiopod biomicrite (wackestone).	1	0	0.30
		14.	Threemile Limestone: variegated (green-gray, yellowish green-gray, gray, and dark gray), shale; shaly bedded, splintery to platy, moderate to well indurated, occasional to locally common rosette crystal molds some filled with white opalline silica: very fossiliferous with crinoids, productid brachiopods (Reticulatia, Linoproductus?, Derbyia, Composita, Neochonetes, Enteletes, echinoids, productid spines, ostracodes, sparse Straparolus, and rare trilobites, most specimens are large (robust) in form and commonly articulated. TA	0	8	0.20
	W1.2	13.	Threemile Limestone: light gray to light yellow-gray, weathers pale yellow-orange and gray, skeletal, coarse calcilutite to calcarenite; nonbedded, massive, blocky, well indurated, cherty, common rectangular and rosette crystal molds in lower 3 in., finer grained in lower 5 in. and less fossiliferous in upper and lower portions of the unit; fossils: sparse Composita (found mostly in central portion of unit), common bryozoa, crinoids, brachiopod shell fragments, sparse echinoids, productid spines, ostracodes, and a 3 in. zone, 10 in. from the base, of abundant, articulated, Wellerella; coarse calcilutite to calcarenite (middle portion): cherty, brachiopod (Wellerella) biomicrite (wackestone).	2	1	0.64
		12.	Speiser Shale: variegated (yellow-gray, green-gray, gray, and dark gray), mottled, shale; shaly bedded, splintery to platy, calcareous, moderate induration; fossiliferous to sparsely fossiliferous with brachiopod shell fragments, Derbyia, small Neochonete, productid brachiopods, Aviculopecten, Enteletes, productid spines, ostracodes, and sparse small bryozoa fragments.	0	4	0.10
		11.	Speiser Shale: variegated (same as unit), shale; shaly bedded, splintery to platy, very calcareous, moderate to well indurated, common argillaceous limestone and shell hash lenses in lower half of unit: very fossiliferous with common Derbyia, Composita, Neochonetes, Reticulatia, crinoids, Aviculopecten, fenestrate and ramose bryozoa, occasional echinoid plates and spines, trilobites, ostracodes, Orbiculoidea shell fragments, productid spines, and Straparolus, fossils are large (robust) in form and commonly articulated, unit becomes less fossiliferous toward top. TA	1	2	0.36
	W1.1	10.	Speiser SHale: variegated (same as unit), shale; shaly bedded, splintery to platy, calcareous, moderate induration, shaly; fossiliferous with Aviculopecten, productid shell fragments, ostracodes, rare to sparse Pinna?, and in the upper 4 to 5 in. sparse Orbiculoidea, Straparolus, and rare small crinoid columnals, unit is less fossiliferous at top and contains common vertical and horizontal burrows throughout.	1	4	0.4

Section RY10 continued

THREEMILE	W1.1	9. Speiser Shale: light gray, with medium gray mottles at top, skeletal calcarenite; nonbedded, blocky, well indurated, sparse to rare small limestone intraclasts near top of unit, occasional large vertical burrows; fossils: <u>Aviculopecten</u>, ostracodes, bivalve shell fragments and sparse to rare <u>Pinna</u>?; fine to medium calcarenite: argillaceous, intraclast bearing ostracode, molluscan biomicrite (wackestone). TA	0	11	0.2
		8. Speiser Shale: green-gray to yellowish green-gray, shale; thinly laminated, platy, moderate induration, occasional lenses of sandy material, calcareous, fossiliferous with sparse ostracodes and shell fragments, also contains common plant fragments and macerals.	0	3	0.08
		7. Speiser Shale: green-gray, upper 0.5 in. is dark gray and green-gray, claystone; nonbedded, blocky, silty, well indurated; sparsely fossiliferous with sparse to rare ostracodes and shell fragments, also contains common to locally abundant (at top of unit) plant fragments and macerals.	0	2.5	0.06
		6. Speiser Shale: green-gray with common yellow-green and black (Mn-oxide?) staining, shale; shaly bedded, platy to blocky; fossiliferous with abundant ostracodes, rare shell fragments, and occasional plant fragments.	0	4	0.10
		5. Speiser Shale: light green-gray to gray, skeletal, calcilutite; single bed, moderate to well indurated, argillaceous and silty, common horizontal burrows, occasional root ? traces; fossiliferous with common to abundant ostracodes, and rare shell fragments; calcilutite: argillaceous ostracode biomicrite (wackestone).	0	2	0.05
		4. Speiser Shale: same as unit 6.	0	5	0.13
FUNSTON		3. Speiser Shale: medium red-gray, with common yellow-green mottles, siltstone; nonbedded, granular, moderate induration, unfossiliferous.	0	9	0.23
		2. Speiser Shale: yellowish green-gray, claystone; nonbedded, granular to slightly platy, silty, moderate induration, common black (Mn-oxide) staining, possible sparse root mottles; unfossiliferous.	0	1.5	0.04
		1. Speiser Shale: green-gray and red-gray (mottled), claystone; nonbedded, granular to blocky, moderate to well indurated, sparse microslickensides, with common dark red-gray root mottles and traces; unfossiliferous.			

Thin-section data was used to supplement descriptions of the following units: 5, 9, and 17.

State: KS County: Riley Quadrangle: Wamego SW

Locality Description:
Roadcuts along the north and south sides of Interstate Highway 70, 5.6 miles east of junction with Interstate Highway 177 (Manhattan exit); N ½, SE ¼, sec. 29, T. 11 S., R. 9 E.

Section RY11

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	ft	in	m
SCHROYER	W2.1	29. Havensville Shale: light orange-gray to light pale yellow-orange, weathers same, skeletal, coarse calcilutite; nonbedded, blocky, occasional vuggy porosity. well indurated; fossils: brachiopod shell fragments, productid spines, fenestrate and ramose bryozoa, sparse *Composita*, echinoid plates and spines, crinoids, ostracodes, and sparse to rare *Derbyia*, unit is cherty with occasional fossil fragments partially replaced by milky white chert; coarse calcilutite: chert bearing, brachiopod biomicrite (wackestone). TA			
THREEMILE	W1.7	28. Havensville Shale: orangish green-gray, shale; thin to thickly laminated, flaggy, moderate induration; fossiliferous at base to very sparsely fossiliferous at top; abundant ostracodes, sparse *Aviculopecten*, and *Permophorus*, unit also contains sparse to locally common plant fossils (white in color). TA	2	8	0.81
	W1.6	27. Havensville Shale: olive to greenish gray with common large areas of yellow-orange mottling, clay shale; indistinct bedding (vague thin laminations apparent on some samples), crumbly (granular) to slightly platy, moderate to poor induration, thin lenses of white, chalky, calcareous material (up to 0.4 in. thick) at top of unit, lower contact somewhat gradational, with occasional, black to brown plant fragments.	0	8.5	0.22
		26. Havensville Shale: medium gray to black, shale; thinly laminated, fissile to platy, moderate to poor induration, very carbonaceous at base (coal smut) with abundant black plant macerals and fragments (mainly stems). TA	0	4	0.10
	- - - - -	- -			
	W1.5	25. Havensville Shale: olive green to green-gray and light gray (mottled), shale; thinly laminated, fissile to platy, moderate to poor induration; occasional thin lenses of medium gray, clay shale; occasional thin (up to 0.8 in. thick) layers of white, chalky, poorly indurated, calcareous material (nodular in form); with abundant yellow-orange plant fragments (leaves and stems) and carbonaceous macerals.	0	8	0.20
		24. Havensville Shale: very pale orange to light orangish gray, weathers pale yellow-orange, skeletal, medium calcirudite; massive, blocky, with large-scale cross-beds apparent in outcrop (paleocurrents indicate a dominant east-northeast transportation), well indurated, porous, slightly silty, unit becomes slightly coarser grained toward the top, unit thins noticably from central portion of outcrop (10 ft. 5 in. at thickest point) outwards; cherty with occasional fossil fragments (mainly bryozoa fragments) partially replaced by microcrystalline and/or chalcedonic quartz; unit contains sparse micrite and silty micrite intraclasts; 0.10 in. average diameter, rounded to subrounded, many are elongate in shape; very fossiliferous: abundant algal (Girvanella?) filaments, common bivalve shell fragments, productid fragments and spines, fenestrate bryozoa fragments, sparse brachiopod shell	10	5	3.18

Section RY11 continued

Formation	Unit	No.	Description	Ft	In	m
THREEMILE	W1.5		fragments, crinoids, echinoids, large and small gastropods, Composita fragments, rare small forams, and ostracodes, upper portion of unit contains sparse tubular, elongate, sponges (?); the lower and middle portions of the rock are composed thin (0.05 in. to 0.17 in.) alternating layers of algal rich and bioclastic rich zones, filamentous algae (Girvanella?) becomes less prevalent toward top; most fossils are fragments and show signs of abrasion (rounded to subrounded), occasional fossil fragments are algal (Osagia) coated, many have micritic envelopes and are highly bored, all elongate allochems are alligned parallel to subparallel to bedding; matrix is mostly microspar and sparry calcite containing sparse to rare pellets and sparse oncolites (up to 2.5 in. diameter); unit contains sparse to locally abundant (on some bedding planes) plant fossils; medium calcirudite: porous, slightly silty, bivalve bearing, Algal (Girvanella) biomicrosparite (wackestone to packstone [locally]). TA			
	W1.4	23.	Havensville Shale: orangish green-gray and dark gray (mottled), shale; shaly bedded, flaggy, moderate induration, common burrows; sparsely fossiliferous at base, unfossiliferous at top; sparse bivalve shell fragments and molds (Permophorus?).	0	9	0.23
		22.	Havensville Shale: brown to green-gray, shale; shaly bedded, flaggy, moderate induration; fossiliferous with sparse productid fragments and spines, chonetids, small crinoid columnals, Derbyia, and ostracodes.	0	4	0.10
		21.	Havensville Shale: medium to light green-gray, shale; shaly bedded, platy to flaggy, very calcareous with occasional argillaceous limestone and shell hash lenses, moderate to well indurated; very fossiliferous with crinoids, Derbyia, Composita, chonetids, productids (Linoproductus, Reticulatia?), fenestrate and ramose bryozoa, echinoid plates and spines, sparse Wellerella, Aviculopecten, Ditomopyge, ostracodes, rare Straparolus, and sharks teeth, most specimens are large (robust) in form and commonly articulated, borings and encrusting bivalves found on some shell surfaces. TA	0	5	0.13
	W1.3	20.	Threemile Limestone: light to medium gray, weathers pale yellow-orange, skeletal, fine calcarenite; indistinct bedding (wavy thin to medium laminations apparent locally), platy to flaggy, argillaceous, well indurated, cherty with occasional small (up to 1.5 in.) calcareous chert nodules; fossils: fenstrate bryozoa fragments, brachiopod shell fragments, productid spines, crinoids, algal (?) fragments, sparse to rare echinoids, and ostracodes; fine calcarenite: argillaceous, cherty, brachiopod, bryozoan biomicrite (wackestone).	0	9	0.23
		19.	Threemile Limestone: very light gray to white, weathers pale yellow-orange, skeletal, medium to coarse calcilutite; nonbedded, blocky, well indurated, porous, slightly chalky, sparse to common rectangular and rosette crystal molds; chert; two major zones in the basal 12 in., and the upper 10 in., the lower zone is a concentration of nodular chert; dark gray and dark blue-gray to very light gray and white, nodules commonly darker in centers, becoming lighter around the edges, occasionally mottled in appearance, fossiliferous same as limestone; the upper zone appears bedded locally but contains areas of nodular chert; description as above; numerous less distinct layers of nodular chert appear between these zones; fossils: fenestrate bryozoa fragments, brachiopod shell fragments, sparse crinoids, echinoids, productid spines, and ostracodes; medium to coarse calcilutite: cherty, brachiopod, bryozoan biomicrite (wackestone).	2	4	0.71

Section RY11 continued

THREEMILE	W1.3	18. Threemile Limestone: very light gray to white, weathers pale yellow-orange, skeletal, coarse calcilutite to fine calcarenite; nonbedded, blocky, chalky, porous, common to locally abundant rosette and rectangular crystal molds, well indurated; chert: one 2 in. to 3 in. thick layer of nodular chert, 12 in. from base; dark gray centers grading outward to very light gray and white edges, fossiliferous same as limestone; fossils: common fenestrate bryozoa, brachiopod shell fragments, sparse Composita, echinoid plates and spines, crinoids, productid spines, and ostracodes; wackestone.	2	7.5	0.80
		17. Threemile Limestone: medium to light gray, weathers pale yellow-orange, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, sparse to locally common rosette and rectangular crystal molds, with a 2 in. thick layer of common to abundant rosettes 8 in. from base; chert; 3 zones; two layers of nodular chert, one 4 in. (3 in. thick) and one 12 in. (4 in. thick) from base; dark gray and dark blue-gray to white, commonly darker toward center of nodules, fossiliferous same as limestone; one layer (6 to 7 in. thick) of bedded chert at top of unit; dark gray and dark blue-gray, occasionally mottled in appearance, sparse opal fracture-fillings, conspicuous rosette crystal molds and ghosts common in this upper bedded chert layer, fossiliferous same as limestone; fossils: fenestrate bryozoa, brachiopod shell fragments, sparse Composita, productid fragments and spines, crinoids, echinoids, and ostracodes; wackestone.	2	3	0.69
		16. Threemile Limestone: yellowish gray, green-gray, and dark gray (mottled), weathers orangish gray, calcareous shale to argillaceous limestone; indistinct bedding, platy to fissile, moderate to well indurated; fossiliferous with brachiopod shell fragments, fenestrate and ramose bryozoa, crinoids, chonetids, Composita, productids (Reticulatia, Linoproductus?), echinoid plates and spines, productid spines, sparse Wellerella ostracodes, and rare trilobite fragments.	0	3	0.08
		15. Threemile Limestone: variegated (yellowish gray, green-gray, pale yellow-orange, and dark gray), mottled, shale; shaly bedded, platy to locally fissile, moderate induration, very calcareous; very fossiliferous with Composita, sparse Derbyia, fenestrate and ramose bryozoa, crinoids, echinoid plates and spines, productids (Reticulatia, Linoproductus), productid spines, chonetids, sparse to rare Straparolus, Enteletes, rare trilobites, and ostracodes, most specimens large (robust) in form, and commonly articulated. TA	0	5	0.13
	W1.2	14. Threemile Limestone: light pale yellow-orange weathers pale yellow-orange, skeletal, coarse calcilutite (at base) to calcarenite; nonbedded, blocky, well indurated, basal 5 in. finer grained (coarse calcilutite) and less fossiliferous than middle portion of unit, common rosette and rectangular crystal molds in basal 5 in.; chert; 3 layers of nodular chert; one 4 in. (6 in. thick), one 14 in. (3 in. thick), and one 21 in. (3 in. thick) from base of unit; dark gray and dark blue-gray to very light gray and white, commonly darker in central portions of nodules, occasionally mottled in appearance, fossiliferous same as limestone; unit is argillaceous in basal and top 1 in.; fossils: fenestrate and ramose bryozoa, brachiopod shell fragments, sparse Composita, crinoids, echinoids, productid spines, ostracodes, rare trilobites, and a 3 in. thick zone of common to abundant Wellerella, 9 in. to 10 in. from base; coarse calcilutite to calcarenite: cherty, bryozoan, brachiopod (Wellerella) biomicrite (wackestone).	2	0	0.61
		13. Speiser Shale: yellowish green-gray and medium gray	0	10	0.2[illegible]

Section RY11 continued

THREEMILE	W1.2	(mottled), weathers light green-gray, shale; shaly bedded, splintery to platy, moderate induration, occasional horizontal burrows, calcareous with shell hash lenses in basal portion of unit; fossiliferous (to sparsely fossiliferous at top) with common Derbyia (in basal portion of unit), sparse small crinoid columnals, bryozoa fragments echinoids, productid spines, sparse to rare Straparolus, ostracodes, and common Enteletes in upper 2 in. to 3 in.			
THREEMILE	W1.2	12. Speiser Shale: yellowish green-gray and medium gray (mottled), weathers light greenish gray, shale; shaly bedded, splintery to platy, very calcareous, moderate to locally well indurated, occasional argillaceous limestone and/or shell hash lenses; very fossiliferous with common to abundant crinoids, Derbyia, Composita, chonetids (Neochonetes), productids (Reticulatia, Linoproductus), echinoid plates and spines, sparse Straparolus, Ditomopyge, Orbiculoidea shell fragments, Aviculopecten(?), productid spines, ostracodes, and rare sharks teeth, most specimens large (robust) in form, and commonly articulated. TA	0	11	0.28
THREEMILE	W1.1	11. Speiser Shale: yellowish green-gray, medium and dark gray (mottled), weathers light greenish gray, shale; shaly bedded, splintery to locally platy, calcareous, poor to moderate induration: sparsely fossiliferous with Orbiculoidea, productid shell fragments and spines, Aviculopecten, Straparolus, and ostracodes.	0	5	0.13
THREEMILE	W1.1	10. Speiser Shale: yellowish green-gray, medium and dark gray (mottled), weathers light greenish gray, shale: shaly bedded, platy to splintery, calcareous, moderate induration; fossiliferous with productid shell fragments and spines, Aviculopecten, ostracodes, and rare echinoid (?) fragments.	1	0	0.30
THREEMILE	W1.1	9. Speiser Shale: medium gray, weathers pale yellow-orange, skeletal, medium calcarenite; thin to medium bedded, blocky to slabby, argillaceous, well indurated, rare small limestone intraclasts; fossiliferous with abundant ostracodes, common bivalve shell fragments, small gastropods, Aviculopecten, rare bryozoa fragments, productid spines, and rare productid fragments at top of unit; medium calcarenite; argillaceous, molluscan, ostracode biomicrite (wackestone). TA	1	4	0.41
THREEMILE	W1.1	8. Speiser Shale: greenish brown, weathers light greenish gray, shale; thin to very thinly laminated, fissile, poor to moderate induration, with common plant fossils; sparsely fossiliferous with ostracodes, and rare bivalve shell fragments.	0	4.5	0.11
THREEMILE	W1.1	7. Speiser Shale: light gray, weathers very light gray, calcilutite: indistrinct bedding (thin to very thin bedding apparent locally), slabby to blocky, well indurated, argillaceous, occasional yellow-orange staining, common vertical and horizontal burrows, sparse possible root(?) traces, sparse argillaceous (and silty) limestone intraclasts; sparsely fossiliferous with ostracodes; calcilutite: argillaceous, intraclast bearing, ostracode bearing micrite (fossiliferous mudstone).	0	7	0.18
FUNSTON		6. Speiser Shale: medium gray to dark gray with yellowish green-gray mottles, claystone; indistinct bedding, crumbly to granular texture, poorly indurated, sparse root (?) mottles, upper 0.5 in. lighter in color and silty, with common to locally abundant carbonaceous films; no fossils found.	0	4	0.10
FUNSTON		5. Speiser Shale: yellowish green-gray, weathers light green-gray, siltstone; nonbedded, blocky, moderate to well indurated, occasional plant fragments, occasional root traces and mottles; unfossiliferous.	1	6	0.46

Section RY11 continued

FUNSTON	4. Speiser Shale: greenish gray, weathers light greenish gray, sandy shale; thick to medium laminations, platy, moderate induration, sandy with occasional granule-sized grains, finer grained toward top; occasional lenses of medium to dark gray, carbonaceous shale (up to 1.5 in. thick) in upper portion of unit; common to abundant plant fossils, sparse angular limestone intraclasts (up to pebble-size); fossiliferous with ostracodes.	0	11	0.28
	3. Speiser Shale: green-gray, weathers light green-gray, siltstone; nonbedded, blocky, well indurated, sandy, occasional large (up to pebble-size) angular limestone intraclasts toward top of unit; sparsely fossiliferous with ostracodes.	0	5.5	0.14
	2. Speiser Shale: medium to light yellowish gray, coarse calcilutite; nonbedded, slabby, well indurated, common micritic limestone intraclasts, abundant fenestral-like porosity, possibly dolomitic (?); very sparsely fossiliferous (?) with rare ostracode (?) shell fragments.	0	6	0.15
	1. Speiser Shale: olive greenish-gray, weathers light green-gray, siltstone; nonbedded, blocky, well indurated, with sparse root mottles; no fossils found			

Thin-section data was used to supplement descriptions of the following units: 7, 9, 14, 17, and 24.

State: KS County: Pottawatomie Quadrangle

Locality Description:
Roadcut on the east side of Highway 99, 0.7 milea south of Pottawatomie County line, NW¼, SW¼, Sec. 3, T. 6 S., R. 9 E.

Section P1

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface ——— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.3	17. Threemile Limestone: light gray, weathers pale yellow-orange and medium dark, akeletal, coarae calcilutite; nonbedded, blocky, moderate to well indurated, porous with abundant vugs, common rosette and rectangular cryatal molds, alightly chalky; Chert: three zones; two layera of bedded chert, one 7 in. (4 in. thick) from baae, one at top of unit (4 in. thick); dark gray to white, commonly mottled in appearance, fossiliferous same as limestone; one layer nodular chert (2 in. thick) 20 inches from base; dark gray centers grading outward to very light gray, fosailiferous same as limestone; fosaila: common <u>Composita</u>, crinoids, brachiopod shell fragments, abundant bryozoa (fenestrate), echinoida, sparae <u>Enteletes</u>, productid apines, and ostracodes.	2	8	0.81
		16. Threemile Limestone: variegated (light gray, yellow-orange, yellowish gray, and green-gray), weathers pale yellow-orange, very calcareous ahale to argillaceoua limeatone; ahaly bedded, platy, moderate induration, occasional to locally common roaette and rectangular crystal molds; fossiliferoua with <u>Composita</u>, crinoids, common amall shell fragments, bryozoa, apa:ae <u>Enteletes</u>, productid spinea, ostracodes, and sparse chonetids.	0	2.5	0.06
		15. Threemile Limeston: pale yellow-orange snd gray (at baae) to light yellowiah gray (at top), weathers pale yellow-orange, skeletal, fine calcarenite; nonbedded, blocky, well indurated, argillaceous at the base, becoming less so toward top, occasional rosette cryatal molds; Chert: two layers of nodular chert, one 1.5 in. (2 in. thick), one 4.5 in. (1.5 in. thick) from the base; dark gray and dark blue-gray centers grading outward to very light gray and white on the borders of the nodules, occasionally mottled in appearance, fossiliferous same as limeatone; fosails: <u>Composita</u>, crinoids, <u>Reticulatia</u>, fenestrate and sparse ramose bryozoa, productid spinea, sparse <u>Enteletea</u>, echinoida, snd ostrscodes; fine calcarenite: slightly srgillsceous, cherty, bryozoan, brachiopod biomicrite (wackestone).	0	7	0.18
		14. Threemile Limeatone: variegated (yellow-orange, yellowish gray, light to dark gray), weathera light yellowish gray, shale; shaly bedded, splintery to platy, very calcareous with occasional argillaceoua limeatone lensea and/or shell hash lensea, well indurated, occasional rectangular and rosette crystal molda; very fossiliferoua with <u>Derbyia</u>, <u>Composita</u>, <u>Neochonetes</u>, <u>Reticulatia</u>, abundsnt crinoid columnsls, productid spines, echinoid platea and spines, fenestrate and ramose bryozoa, sparse <u>Enteletes</u>, <u>Straparolua</u>, ostracodea, and rare trilobite frsgments most specimens are large (robuat) in form and commonly articulated. TA	0	5	0.13
	W1.2	13. Threemile Limeatone: light yellowish gray, weathers pale yellow-orange to gray, skeletal, fine calcsrenite; nonbedded, blocky, well indurated, argillaceous in the upper 1 in.; fosails: common brachiopod ahell fragments, crinoids, feneatrate and sparse ramoae bryozoa, productid spines, echinoid fragments, ostracodes, and rare	0	9	0.23

Section P1 continued

THREEMILE	W1.2	13. (cont.) Aviculopinna?; Chert; 3 in. thick layer of bedded chert 4 in. from base; dark gray and dark blue-gray to very light gray and white, occasionally mottled, fossiliferous same as limestone; fine calcarenite: cherty, bryozoan, brachiopod biomicrite (wackestone).			
		12. Speiser Shale: yellowish green-gray, shale; indistinct bedding, poor induration, calcareous; very sparsely fossiliferous with brachiopod shell fragments.	0	1.5	
		11. Speiser Shale: greenish gray, yellowish green-gray, and and yellowish orange (mottled), weathers light green-gray, shale; shaly bedded, splintery to platy, moderate induration; fossiliferous with small crinoid columnals, productid shell fragments (Reticulatia) and spines, sparse Derbyia, chonetids, Aviculopecten, Orbiculoidea shell fragments, bryozoa, and ostracodes.	0	4	0.10
		10. Speiser Shale: greenish gray, yellowish green-gray, and yellow-orange (mottled), weathers light green-gray, shale; shaly bedded, splintery to platy, very calcareous with occasional shell hash lenses, moderate to well indurated; very fossiliferous with Derbyia, Composita, Reticulatia, crinoids, Neochonetes, echinoid plates and spines, sparse Aviculopecten, Orbiculoidea shell fragments and ramose bryozoa, ostracodes, rare trilobite fragments, and rare fragmentary vertebrate remains (sharks teeth), most specimens are large (robust) in from and commonly articulated, unit becomes less fossiliferous toward top. TA	0	8	0.20
	W1.1	9. Speiser Shale: greenish gray, and yellowish green-gray, weathers light green-gray, shale; shaly bedded, platy, calcareous, moderate induration; fossiliferous with common Orbiculoidea shell fragments (with only a few whole specimens found), Aviculopecten, sparse productid shell fragments and spines, Straparolus, and ostracodes.	0	2.5	
		8. Speiser Shale: greenish gray, and yellowish green-gray, weathers light green-gray, shale; indistinct shaly bedding, splintery to platy, calcareous, moderate induration; fossiliferous with productid shell fragments and spines, Aviculopecten, Aviculopinna?, and ostracodes.	1	0	0.30
		7. Speiser Shale: light yellowish gray to light gray, weathers light to dark gray, skeletal, coarse calcilutite to fine calcarenite (wackestone); nonbedded, blocky, well indurated; fossils: bivalve shell fragments, Aviculopecten, sparse Aviculopinna? (possibly Pinna), and rare small gastropods. TA	0	8	0.20
FUNSTON		6. Speiser Shale: green to yellowish green-gray, shale; indistinct shaly bedding, platy, calcareous, moderate induration, occasional dark gray root(?) mottles; no fossils found.	0	2	0.05
		5. Speiser Shale: light greenish gray to yellowish green-gray, weathers same, silty claystone; nonbedded, blocky, moderate induration, calcareous; upper 2.5 in. less indurated and lighter in color; common yellow-orange to green root mottles; unfossiliferous.	1	7	0.48
		4. Speiser Shale; green to green-gray, weathers light green-gray, silty claystone; nonbedded, blocky, calcareous, with occasional to common root mottles; unfossiliferous.	0	5	0.13

Section P1 continued

FUNSTON	3. Speiser Shale: green to green-gray, weathers light green-gray, silty clayston; nonbedded, granular, moderate to poor induration, slightly calcareous, with occasional to common root mottles; unfossiliferous.	0	8	0.20
	2. Speiser Shale: green to green-gray, weathers light greenish gray, silty claystone; nonbedded, blocky, well indurated, calcareous, forms slight ledge in outcrop, with common root mottles; unfossiliferous.	0	9	0.23
	1. Speiser Shale: red to dark red-gray, weathers reddish gray, silty claystone; nonbedded, blocky,moderate induration, with common root mottles; unfossiliferous.			

State: KS County: Pottawatomie Quadrangle: Onega NE

Locality Description:

Roadcuts on the east side state highway 63, 0.2 miles north of intersection with Highway 16, NE¼, SW¼, Sec. 34, T. 6 S., R. 12 E.

Section P2

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
THREEMILE	W1.3	12. Threemile Limestone: light gray to light orsngish gray, weathers medium gray, skeletal, coarse calcilutite (wackeatone); nonbedded, blocky, moderate to well indurated, porous with abundant vugs, common rosette crystal molds; Chert; two layers of nodular chert, 2 in. (2 in. thick) and 10 in. (2 in. thick) from base of unit; dark gray in center grading outward to very light gray and white on borders, fossiliferous same as limestone; fossils: fenestrate and aparse ramose bryozoa, crinoids, echinoid plates and spines, productid shell fragments (Reticulatia?) and spines, sparse Composita, and ostracodes.	1	3	0.38
		11. Threemile Limestone: dark gray and dark blue-gray to very light gray and white chert, occasionally mottled in appearance, common irregulsrly shaped patches of cherty limestone; fossiliferous with fenestrate and ramose bryozoa, crinoids, echinoid plates and spines, productid shell fragments and spines, sparse Composita, and ostracodes.	0	6.5	0.17
		10. Threemile Limestone: same as unit 12	0	3	0.08
		9. Threemile Limestone: same as unit 11			
		8. Threemile Limestone: medium gray, yellowish gray, and pale yellow-orange (mottled), skeletal, srgillaceous, coarse calcarenite to calcirudite (packstone); nonbedded, blocky, well indurated, lighter in color and not ss mottled at top, less argillaceous toward top, common rosette crystal molds; very fossiliferous: sbundant crinoids, common Composita, Reticulatia, chonetids, fenestrate and ramose bryozoa, echinoid plates and spines, Derbyia, productid spines, sparse ostracodes, rare trilobite fragments, and Pinna(?) most specimens are large (robust) in form and commonly articulated, fossils become less abundant toward top of unit; Chert; one layer bedded chert (3 in. thick), 4 in. from base of unit; dark gray snd dark blue-gray to white, occasionally mottled in appearance, fossiliferous same as limestone. TA	0	11	0.28
	W1.2	7. Threemile Limestone: light to medium gray, westhers pale yellow-orange, akeletal, fine calcarenite (wackestone); nonbedded, blocky, well indurated, occasional to locally common rosette and rectangular crystal molds, abundant vugs in a 2 in. thick zone 10 in. from base; Chert; two layers of nodular chert, one 12 in. (2 in. thick) one 21 in. (1 in. thick) from base of unit; dark gray centers grading outward to very light gray and white borders, fossiliferous same as limestone, occasional cherty limestone nodules at top of unit; fossils: brachiopod shell fragments, crinoids, echinoid plates and spines, productid shell fragments and spines, sparse Composita, fenestrate and ramose bryozoa, and ostracodes.	2	2	0.66
		6. Speiser Shale: yellowish green, light and dark gray (mottled), shale: ahaly bedded, splintery to platy, moderste induration, occasional thin (up to 0.25 in. thick) argillaceous limestone lenses; sparsely fossiliferous with brachiopod shell fragments, ostracodes, and sparse bivalve shell fragments.	0	6	0.15

Section P2 continued

THREEMILE	W1.2	5. Speiser Shale: yellowish green, light and dark gray (mottled), shale: indistinct shaly bedding, flaggy to splintery, moderate to well indurated, very calcareous with occasional argillaceous limestone and/or shell hash lenses; very fossiliferous with crinoids, Derbyia, Reticulatia, Neochonetes, fenestrate and ramose bryozoa, echinoid plates and spines, productid spines, sparse Composita, ostracodes, and trilobites, most specimens large (robust) in form and commonly articulated. TA	0	6	0.15
	W1.1	4. Speiser Shale: yellowish green, light to medium gray (mottled), shale; indistinct shaly bedding, platy, calcareous with occasional very thin (up to 0.05 in.) limestone lenses, occasional calcite geodes; sparsely fossiliferous with common Orbiculoidea, shell fragments, ostracodes, and sparse unidentifiable shell fragments.	0	3	0.08
		3. Speiser Shale: yellowish green, light and medium gray (mottled), shale: indistinct shaly bedding, platy, calcareous, occasional calcite geodes, common horizontal burrows; sparsely fossiliferous with bivalve shell fragments, ostracodes, rare Aviculopecten, and unidentifiable shell fragments.	1	0	0.30
		2. Speiser Shale: light yellow-orange, medium and dark gray (mottled), skeletal, fine calcarenite (wackestone) nonbedded, blocky, well indurated, abundant horizontal and vertical burrows in upper 4 in. to 5 in.; fossils: common bivalve shell fragments, abundant ostracodes, rare productid spines(?), rare small crinoid columnals and rare bryozoa fragments. TA			
		?——————?——			
FUNSTON		1. Speiser Shale: light yellowish green, and medium to dark gray (mottled), silty clayston; nonbedded, blocky, occasional coarse granule-sized calcareous nodules, moderate induration, occasional microslickensides; rare possible ostracode shell(?) fragments. Only 7 inches exposed.			

State: KS County: Pottawatomie Quadrangle: Onega NE

Locality Description:
Roadcuts on the south side of state Highway 16, 0.2 miles west of junction (northern) with Highway 63, NW¼, NE¼, sec. 4, T. 7 S., R., 12 E.

section P3

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— ---Climate Change Surface	Unit Thicknesses ft	in	m
THREEMILE	W1.3	7. Threemile Limestone: light yellowish gray, weathers pale yellow orange, skeletal, coarse calcilutite; nonbedded, blocky, well indurated, occasional rosette crystal molds, slightly argillaceous at base; Chert: two layers of nodular chert, one 3 in., (3 in. thick), one 13 in. (2 in. thick) from base of unit; dark gray centers grading outward to very light gray and white on borders, fossiliferous same as limestone; fossils, fenestrate and sparse ramose bryozoa, brachiopod shell fragments, crinoids, echinoids, productid shell fragments and spines, sparse <u>Composita</u>, and ostracodes.	1	5	
		6. Threemile Limestone: pale yellow-orange, yellowish gray, and medium gray (mottled), argillaceous limestone to very calcareous shale; shaly bedded, platy, well indurated, occasional rosette crystal molds; fossiliferous with productid shell fragments (<u>Reticulatia</u>?) and spines, crinoids, fenestrate and ramose bryozoa, sparse <u>Composita</u>, <u>Derbyia</u>, chonetids, ostracodes, echinoid plates and spines and rare trilobite fragments. TA			
	W1.2	5. Threemile Limestone: light yellowish gray to gray, weathers pale yellow-orange, skeletal fine calcarenite; nonbedded, blocky, well indurated, argillaceous and less fossiliferous in upper 1 in.; Chert; 2 in. thick layer of nodular chert, 3.5 in. from base; dark gray centers grading outward to very light gray and white on borders, fossiliferous same as limestone; fossils: brachiopod shell fragments, fenestrate and ramose bryozoa, sparse crinoids, echinoids, productid shell fragments and spines, ostracodes, and rare <u>Composita</u>.	0	8	0.20
		4. Speiser Shale: yellowish gray, yellowish green gray, light to medium gray (mottled), weathers light greenish gray, shale; shaly bedded, platy, calcareous to very calcareous at base, occasional argillaceous limestone lenses in basal 4 in. of unit; very fossiliferous at base to sparsely fossiliferous at top; crinoids, fenestrate and ramose bryozoa, <u>Derbyia</u>, <u>Composita</u>, productid shell fragments (<u>Reticulatia</u>) and apines, echinoid plates and spines , chonetids, ostracodes, and rare trilobite fragments. TA	0	7.5	0.19
	W1.1	3. Speiser Shale: yellowish gray, yellowish green-gray, light to medium gray (mottled), weathers light greenish gray, shale; shaly bedded, platy, moderate induration; sparsely fossiliferous with productid shell fragments and spines, <u>Aviculopecten</u>(?), ostracodes, and rare small ramose bryozoa fragments, sparse phosphatic shell fragments (<u>Orbiculoidea</u>?) found in upper 2 in., less fossiliferous toward top.	0	8	0.20

Section P3 continued

THREEMILE	W1.1	2. Speiser Shale: yellowish gray, light and medium gray (mottled), weathers light yellow-orange to gray, skeletal, fine calcarenite; nonbedded at top to very thinly bedded at base, blocky to slabby, well indurated, lower 5 inches composed of interbedded limestone and shale; shale is green-gray and fossiliferous with ostracodes and bivalve shell fragments; fossils: bivalve shell fragments, abundant ostracodes, rare productid spines, rare small bryozoa (ramose) fragments, and rare small crinoid columnals, less fossiliferous toward base. TA	1	5	0.43
FUNSTON		1. Speiser Shale: light yellowish green, and medium gray (mottled), silty claystone; nonbedded, blocky, occasional calcareous nodules, moderate to locally poor induration; no fossils found.			

State: KS County: Pottawatomie Quadrangle: Westmoreland

Locality Description:

Roadcuts along the east side of Interstate Highway 99, 5 miles north of Westmoreland, Kansas, at SW¼. SW¼. sec., 3, T. 7 S.,, R. 9 E..

Section P4

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – – Climate Change Surface	Unit Thicknesses ft	in	m
SCHROYER	W2.1	29. Schroyer Limestone: light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, fine calcarenite (wackestone); thick bedded, well indurated, occasional siliceous geodes, occasional rosette and rectangular crystal molds; Chert; three zones; two layers of nodular chert, one at the base, one 1 to 2 in. from the top, dark gray to light gray, weathers very light gray to white; fossiliferous same as limeatone; one layer bedded chert, 6 to 7 in. thick, dark gray to light gray, occaaional patches of calcareous material, opal fracture fillinos; fossiliferous same as limestone; fossils: Composita, brachiopod shell fragments, fenestrate bryozoa, crinoids, echinoids, aparse Derbyia, Reticulatia, productid spines, sparse chonetids, and oatracodes.	2	0	0.61
		28. Schroyer Limestone: yellowish gray, shale; very calcareous, shaly bedded, slightly silty; fossiliferous with Composita, Derbyia, chonetids, fenestrate and sparse ramose bryozoa, crinoids, sparse echinoids, productid apines, ostracodes and rare fish teeth.	0	5	0.13
		27. Schroyer Limestone: light gray to light pale yellow-orange, skeletal, fine calcarenite (wackestone); thick-bedded, well indurated, occasional rectangular and rosette crystal molds; Chert; two layers of nodular chert, one 2 in. from base, one 2 to 3 in. from top of unit, light gray to medium dark gray; fossiliferous same limestone, both 3 to 4 in. from top of unit, light gray to medium dark gray; fossiliferous same limestone, both 3 to 4 in. thick; fossils: Composita, productids, brachiopod shell fragments, fenestrate and ramose bryozoa, crinoids, echinoids, productid spines, and ostracodes.	0	11	0.28
THREEMILE	W1.7	26. Havensville Shale: medium to dark gray, claystone; nonbedded, moderate to poorly indurated, calcareous, common collapse structures in the lower portion of the unit, unfossiliferous, with occasional calcareous nodules.	3	0	0.91
		25. Havensville Shale: light gray and light yellowish gray, skeletal, calcilutite; thick to medium bedded, moderate to locally poor induration; fossils: small gastropods (high and low spired), and bivalve shell fragments.	2	9	0.84
	W1.6	24. Havensville Shale: green-gray to medium gray, mudstone; silty to locally sandy, thin bedded, slightly calcareous, 3 to 4 in. zone of collapse structures 8.5 in. from the top of the unit, very sparsely fossiliferous with rare bivalve (nuculoid like) molds only found in the basal 2 feet.	5	8	1.73
		23. Havensville Shale: green-gray to medium gray, calcilutite; very argillaceous, moderate to locally poor induration, thin bedded; very sparsely fossiliferous with sparse to rare shell (bivalve?) fragments. TA			

Section P4 continued

THREEMILE	W1.5	22. Havensville Shale: green-gray to gray, mudstone; sandy, nonbedded, calcareous, sparse small calcareous nodules, unfossiliferous.	0	9	0.23
		21. Havensville Shale: green-gray to medium gray, mudstone; calcareous, thin bedded to laminated, moderate induration, no fossils found.	1	9	0.53
		20. Havensville Shale: dark reddish gray, yellowish gray and medium gray (mottled), skeletal, coarse calcarenite to calcirudite; thin bedded, argillaceous (to very argillaceous in lower half), moderate to well indurated; Fossils: common to abundant Aviculopecten, small gastropods, sparse productid spines, bivalve shell fragments, sparse small bryozoa fragments, and sparse ostracodes. TA	0	6	0.15
	W1.4	19. Havensville Shale: olive gray to dark gray (mottled), shale; silty, calcareous, blocky to platy, horizontal burrows (Chondrites?); sparsely fossiliferous with Aviculopecten, bivalve shell fragments, sparse to rare small crinoid columnals, and ostracodes.	2	11	0.89
		18. Havensville Shale: green-gray and dark gray (mottled), shale; very calcareous, shaly bedded, occasional thin lenses of limestone; very fossiliferous with ramose and fenestrate bryozoa, Composita, Derbyia, chonetids, productids, productid spines, crinoids, echinoids, sparse Aviculopecten, trilobite fragments, and ostracodes. TA	0	9	0.23
	W1.3	17. Threemile Limestone: light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, calcarenite; thin bedded, slightly argillaceous to argillaceous, moderate to well indurated, sparse small siliceous geodes and sparse to rare small chert nodules and patches; fossils: bryozoa fragments, brachiopod shell fragments, crinoids, echinoids, productid spines, and sparse ostracodes, fossils are mostly fragmented and many appear abraded.	0	6	0.15
		16. Threemile Limestone: light gray, weathers pale yellow-orange, skeletal, calcarenite; thick bedded, well indurated, cherty, occasional rosette and rectangular crystal molds; Chert; two layers of nodular chert, one at the top of the unit (3 in. thick), one at the base of the unit (4 in. thick), both light gray to medium gray, weathers very light gray to white, sparse opal fracture-fillings; fossiliferous same as limestone; fossils: ramose and fenestrate bryozoa, Composita, Enteletes, brachiopod shell fragments, productid spines, crinoids, echinoids, sparse to rare Derbyia, sparse chonetids, and ostracodes.	0	10	0.25
		15. Threemile Limestone: very light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, calcarenite; thick bedded (massive), well indurated, chalky, common solution pits, porous with common rosette crystal molds; Chert; three layers 2 to 3 in. thick, of nodular chert, 4 in., 10 in., and 16 in., from the base of the unit, light to medium and dark gray, occasional opal fracture-fillings, fossiliferous same as limestone; fossils: fenestrate and ramose bryozoa, Composita, Enteletes, brachiopod shell fragments, productid spines, crinoids, echinoids, sparse Derbyia, and ostracodes.	3	10	1.17

Section P4 continued

THREEMILE	W1.3	14. Threemile Limestone: light to medium gray, weathers yellowish gray, skeletal, coarse calcarenite (wackestone); thin bedded, cherty, slightly argillaceous, occasional rosette crystal molds; fossils: Composita, Enteletes, fenestrate and ramose bryozoa, crinoids, echinoids, productids (Reticulatia?), productid spines, sparse Derbyia, brachiopod shell fragments, and ostracodes.	0	7	0.18
		13. Threemile Limestone: light to medium gray, shale; very calcareous, shaly bedded, moderate to well indurated, common lenses of argillaceous limestone; very fossiliferous with Derbyia, Enteletes, productids (Reticulatia?), Composita, fenestrate and ramose bryozoa, crinoids, echincoids, sparse to rare trilobite fragments, productid spines, and ostracodes. TA	0	5	0.13
	W1.2	12. Threemile Limestone: light pale yellow-orange, weathers pale yellow-orange, skeletal, calcarenite (wackestone); thick bedded, well indurated, slightly finer grained and less fossiliferous in the basal portion of the unit, upper 1 in. slightly argillaceous, occasional siliceous geodes, occasional rectangular crystal molds, cherty; Chert; one layer of bedded chert, 3 to 4 in. thick, 2 in. from the top of the unit; light gray to medium gray, weathers very light gray to white, occasional opal fracture-fillings, fossiliferous same as limestone; fossils: fenestrate and remose bryozoa, brachiopod shell fragments, productid spines, crinoids, echinoids, sparse to rare chonetids, and ostracodes.	0	9	0.23
		11. Speiser Shale: green-gray, yellowish gray, and light gray (mottled), shale; calcareous, shaly bedded, poor to moderate induration; sparsely fossiliferous with brachiopod shell fragments, productid framents, small crinoid columnals, sparse to rare bryozoa fragments, and ostracodes, becomes very sparsely fossiliferous to unfossiliferous in upper 2 inches.	0	6	0.15
		10. Speiser Shale: green-gray, yellowish gray, and light to medium gray (mottled), shale; very calcareous, shaly bedded, moderate to well indurated, occasional small calcite geodes, sparse thin argillaceous limestone lenses; very fossiliferous with Derbyia, Composita, Neochonetes, fenestrate and ramose bryozoa, Linoproductus, crinoids, echinoids, productid spines, sparse to rare trilobits, rare sharks teeth, and ostracodes, slightly less fossiliferous at top of unit. TA	0	7	0.18
	W1.1	9. Speiser Shale: green-gray, light gray and medium gray (mottled), shale; calcareous, shaly bedded, moderate induration, common calcite geodes (average diameter 0.5 in.); fossiliferous with Aviculopecten, Orbiculoidea, sparse small crinoid columnals, ostracodes, and sparse to rare Straparolus.	0	3.5	0.09
		8. Speiser Shale: green-gray, light gray and medium gray (mottled), shale; calcareous, shaly bedded, moderate to locally poor induration, common irregular lenses of crystalline calcite (secondary in nature), common horizontal and vertical burrows; fossiliferous with productid shell fragments, sparse Aviculopecten, productid spines, and ostracodes.	0	10	0.25
		7. Speiser Shale: light yellowish gray to pale yellow-orange and medium gray, skeletal, calcarenite; medium bedded, well indurated, basal 1 in. finer grained (calcilutite), argillaceous, and less fossiliferous; fossiliferous with common bivalve shell fragments, ostracodes, Aviculopecten, and sparse productid spines. T2	0	7	0.18

Section P4 continued

Formation	Unit	Description	ft	in	m
THREEMILE	W1.1	6. Speiser Shale: light yellow-gray and pale yellow-orange (mottled), claystone; nonbedded, granular texture, poor induration, slightly silty, occasional thin (up to 0.5 in.), light gray, limestone lenses; fossiliferous with ostracodes, and rare shell fragments.	0	3	0.08
		5. Speiser Shale: green-gray, claystone; nonbedded, calcareous, blocky, moderate induration, common black Mn-oxide staining; sparsely fossiliferous with ostracodes and rare shell fragments.	0	4	0.10
FUNSTON		4. Speiser Shale: light gray, medium gray, yellow-gray, and green-gray (mottled), claystone; nonbedded, calcareous, silty, poor to locally well indurated, occasional black Mn-oxide staining; no fossils seen.	0	4	0.10
		3. Speiser Shale: green to green-gray, claystone; nonbedded, silty, calcareous, blocky, moderate to well indurated, occasional black (Mn-oxide) and yellow-orange staining; unfossiliferous.	0	3	0.08
		2. Speiser Shale: light gray and green-gray to medium gray (mottled), claystone; nonbedded, silty, granular to blocky, common black (Mn-oxide?) staining, sparse black macerals? or carbonaceous? films, unfossiliferous, with common medium gray root mottles.	2	10	0.86
		1. Speiser Shale: reddish gray to red-brown, claystone; nonbedded, silty, blocky, well indurated; unfossiliferous; with common to abundant root traces and mottles.			

State KS County: Marshall Quadrangle Blue Rapids

Locality Description.

Roadcuts on the west side of Interstate route 77, 0.1 to 0.2 miles north of intersection with Route 9, at c., SE¼, sec. 16, T. 4 S., R. 7 E., in Marshall County, Kansas.

Section M1

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – – Climate Change Surface	Unit Thicknesses ft	in	m
THREEMILE	W1.5	18. Havensville Shale: olive green-gray and dark gray, shale; indistinct to shaly bedded, silty, slightly calcareous, horizontal burrows (Chondrites); sparsely fossiliferous with bivalve shell fragments, Permophorus? and Aviculopecten; accuracy of description limited by heavy vegetation and soil coverage.	3	7	1.09
		17. Havensville Shale: medium gray, yellow-gray, with occasional dark gray (mottled), skeletal, coarse calcarenite (wackestone); thinly bedded, argillaceous, moderate to well indurated; fossils: Aviculopecten, bivalve shell fragments, sparse small gastropods, productid spines, ostracodes, and rare small bryozoa fragments. TA	0	5	0.13
	W1.4	16. Havensville Shale: green-gray to dark gray (mottled), shale; shaly bedded, silty, calcareous, blocky to platy; sparsely fossiliferous with bivalve shell fragments, Aviculopecten, sparse to rare small crinoid columnals, and ostracodes; accuracy of description limited by heavy vegetation and soil coverage.	1	8	0.51
		15. Havensville Shale: light gray, green-gray, and medium to dark gray, weathers light green-gray, shale; very calcareous, shaly bedded, platy, moderate to well indurated, occasional to common shell hash lenses; very fossiliferous with abundant to common Derbyia, Composita, Enteletes, Meekella, crinoids, fenestrate and ramose Bryozoa, Reticulatia, Linoproductus, chonetids, echinoid plates and spines, and sparse Crurythyrus, Rhipidomella, Straparolus, productid spines, and ostracodes, most specimens are articulated and large (robust) in form, commonly found in life position. TA	0	6	0.15
	W1.3	14. Threemile Limestone: light gray to light yellow-gray and medium gray (mottled), weathers yellow-gray, skeletal, calcarenite; thinly bedded, argillaceous, well indurated; fossils: fenestrate bryozoa fragments, brachiopod shell fragments, sparse crinoids, echinoids, productid spines, and ostracodes, all fossils are fragmented.	0	4	0.10
		13. Threemile Limestone: very light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, coarse calcilutite to calcarenite (wackestone); massive, moderate to well indurated, chalky, porous with common solution pits and vugs, occasional to locally common rosette and rectangular crystal molds; Chert; three zones; two layers of bedded chert, both 3 in. thick,one at the top, one 7 in. from the top, dark gray to light gray, occasional opal fracture-fillings, fossiliferous same as limestone; one layer of nodular chert, 3 in. thick, 11 in. from base of unit, dark gray to medium gray in the central portions of the nodules, fossiliferous same as limestone; fossils: common to locally abundant fenestrate bryozoa, common brachiopod shell fragments, sparse Composita, Enteletes, productid spines, crinoids, echinoids, and ostracodes.	3	10.5	1.18

Section M1 continued

THREEMILE	W1.3	12. Threemile Limestone: light to medium gray and light yellow gray, skeletal, coarse calcilutite to calcarenite; shaly bedded, argillaceous, well indurated; fossils: brachiopod shell fragments, fenestrate bryozoa fragments, productid spines, and ostracodes, unit appears as a thin shaly parting in the upper Threemile Limestone.	0	2.5	0.06
		11. Threemile Limestone: same as unit 13, 4 in. zone of nodular chert, 2 in. from top of unit.	0	10	0.25
		10. Threemile Limestone: same as unit 12.	0	2.5	0.06
		9. Threemile Limestone: light gray to light pale yellow-orange, darker in lower portion (medium gray to light pale yellow-orange, mottled), skeletal, calcarenite (wackestone); nonbedded, well indurated, argillaceous in lower portion; occasional rectangular and rosette crystal molds; fossils: fenestrate and ramose bryozoa, brachiopod shell fragments, productid spines, productid brachiopods (Reticulatia?), crinoids, sparse echinoids, ostracodes, and sparse to rare Composita, unit is more fossiliferous toward the base.	1	0	0.30
		8. Threemile Limestone: medium to dark gray, light yellow-gray, and green-gray (mottled), shale; very calcareous, shaly bedded, well indurated, fossiliferous with brachiopod shell fragments, fenestrate and remose bryozoa, echinoids, crinoids, sparse Derbyia, Composita, chonetids (mainly Neochonetes), productid brachiopods (Reticulatia?), productid spines, ostracodes, and rare trilobites. TA	0	4	0.10
	W1.2	7. Threemile Limestone: light gray to light pale yellow-orange, skeletal, calcarenite; thick bedded, to massive, well indurated, slightly argillaceous at the top; cherty; Chert; 3 to 4 in. layer of bedded chert, 2 to 3 in. from top of unit, dark gray to light gray (locally mottled in appearance), occasional patches of calcareous material, fossiliferous same as limestone; fossils: fenestrate and ramose bryozoa, brachiopod shell fragments, sparse crinoids and echinoids, productid spines, and ostracodes, accuracy of description limited do to thick soil and vegetation coverage.	0	10	0.25
		6. Speiser Shale: green-gray, gray, and dark gray (mottled), shale; calcareous, shaly bedded, silty, moderate induration; sparsely fossiliferous with brachiopod shell fragments, chonetids?. bryozoa, small crinoid columnals, echinoids, productid spines, and ostracodes, unit becomes very sparsely to unfossiliferous at the top; accuracy of description limited do to thick soil coverage.	0	8	0.20
		5. Speiser Shale: green-gray, gray, dark gray (mottled), shale; very calcareous, shaly bedded, moderate to well indurated, occasional argillaceous skeletal limestone lenses fossiliferous with crinoids, fenestrate and ramose bryozoa, Derbyia, Composita, Neochonetes, productid brachiopods (Reticulatia), productid spines, sparse Straparolus, Orbiculoidea shell fragments, ostracodes, and rare trilobites, most specimens large (robust) in form; accuracy of description limited do to thick soil coverage. TA	0	11	0.28
	W1.1	4. Speiser Shale: green-gray, gray, and dark gray (mottled), shale; calcareous, shaly bedded, moderate induration; fossiliferous to sparsely fossiliferous with Aviculopecten, Orbiculoidea shell fragments, sparse small crinoid columnals Straparolus, ostracodes, small bryozoa fragments, and rare Aviculopinna?; accuracy of description limited do to soil coverage.	0	3.5	0.09

Section M1 continued

THREEMILE	W1.1	3. Speiser Shale: green-gray, gray, and dark gray (mottled) shale; calcareous, shaly bedded, moderate induration; fossiliferous with <u>Aviculopecten</u>, productid shell fragments and spines, and ostracodes.	1	6	0.46
		2. Speiser Shale: light gray to light yellow-gray, weathers yellow-gray, skeletal, calcarenite; single bed, well indurated, slightly argillaceous in upper 1 in.; fossils: <u>Aviculopecten</u>, bivalve shell fragments, ostracodes, sparse to rare <u>Septimyalina</u>, productid spines, and rare <u>Aviculopinna</u>?.	1	2	0.36
		1. Speiser Shale: green-gray, weathers light green-gray, claystone; nonbedded, blocky, silty, moderate to well indurated; fossiliferous with ostracodes, and sparse to rare shell fragments.			

State: KS County: Wabaunsee Quadrangle: Alma

Locality Description:
Roadcuts along the north side of Interstate Route 70, 1.1 to 1.3 miles west of the Alma, Wamego exit in Wabaunsee County at SW¼, NW¼, sec. 28, T. 11 s., R. 10 E.

Section W1

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
SCHROYER	W2.1	32. Havensville Shale: very light gray to yellowish gray, weathers yellow-gray, skeletal, coarse calcilutite; thick to medium bedded, blocky to flaggy, well indurated; fossils: fenestrate and ramose bryozoa, crinoids, Composita, Reticulatia, echinoid spines, productid spines, common brachiopod shell fragments, and ostracodes.	1	1	0.33
THREEMILE	W1.7	31. Havensville Shale: green-gray and yellowish green-gray, claystone; nonbedded, blocky to puddy-like testure locally, moderate to poor induration, upper 10 in. contains common calcareous nodules (up to 3 in.) and patches of soft, white calcareous material, upper 10 in. also lighter in color (light green-gray); sparse plant fragments becoming more abundant toward the top of the unit.	2	4	0.71
		30. Havensville Shale: dark gray, weathers light gray to yellowish gray, skeletal, coarse calcilutite; single bed, blocky, well indurated; fossils: abundant small high spired gastropods, and bivalve shell fragments, and productid spines; coarse calcilutite: molluscan biomicrite, (packestone).	0	2	0.05
	W1.6	29. Havensville Shale: green-gray to yellowish green-gray, claystone; nonbedded, blocky to puddy-like texture, common calcareous nodules; upper 1/8 in. pale yellow-white, calcareous, claystone; occasional plant fragments.	0	4	0.10
		28. Havensville Shale: dark gray, weathers light gray to pale yellow-orange, intraclastic, skeletal, calcirudite; single bed, well indurated, argillaceous, occasional plant fragments, sparse to rare micritic limestone intraclasts (up to 0.2 in.); fossils: bivalve shell fragments, Aviculopecten, sparse ostracodes, and rare brachiopod shell fragments, many of the bivalve and all brachiopod shell fragments are algal (Osagia) coated (coating up to 0.4 mm thick); calcrudite: intraclast bearing, argillaceous, bivalve biomicrite, (packestone).	0	3	0.08
		27. Havensville Shale: yellowish green to green gray, weathers light greenish gray, claystone; nonbedded, silty, blocky, moderate to poor induration; occasional plant fragments; fossiliferous with sparse ostracodes, and shell fragments.	1	0	0.3
	W1.5	26. Havensville Shale: green and yellowish green with dark gray mottles, claystone: nonbedded, silty, poorly indurated with a puddy-like texture, occasional to common black carbonaceous films or masserals, occasional white (caliche-like) calcareous nodules (up to 0.4 in.); rare to locally sparse plant fragments.	5	4.5	1.6

Section Wl continued

THREEMILE	W1.5	25.	Havensville Shale: olive greenish-gray and dark gray (mottled), weathers light green-gray, shale; indistinct bedding, flaggy, moderate induration, common to locally abundant horizontal burrows (Chondrites?), occasional thin (up to 0.5 in.) micritic, dark gray, limestone, lenses, limestone lenses common at base of unit; sparsely fossiliferous with sparse *Aviculopecten*, ostracodes, rare *Permopherus*, and shell fragments.	5	4.5	1.64
THREEMILE	W1.5	24.	Havensville Shale: green-gray with dark gray (mottled), weathers medium to dark greenish gray, shale; shaly bedded, flaggy to platy, silty, moderate induration, common green-gray horizontal burrows (Chondrites); sparsely fossiliferous with sparse *Aviculopecten*, rare *Permopherus*, and rare shell fragments.	6	1	1.85
THREEMILE	W1.5	23.	Havensville Shale: medium gray, weathers light gray to light yellowish gray, skeletal, calcirudite; thinly bedded, argillaceous, slabby, well indurated: fossils: *Aviculopecten*, small high spired gastropods, sparse *Permopherus*, sparse productid spines, bryozoa fragments, forams (Tetrataxis?), rare crinoids, and echinoids; slightly bioturbated: calcirudite: argillaceous, molluscan biomicrite (packestone).	0	7	0.18
THREEMILE	W1.4	22.	Havensville Shale: greenish gray and dark gray (mottled), weathers medium gray, shale; indistinct bedding, flaggy, moderate induration, sparse lenses of concentrated shell debris; sparsely fossiliferous with sparse *Aviculopecten*, bivalve shell fragments, ostracodes, and rare small crinoid columnals.	1	3	0.38
THREEMILE	W1.4	21.	Havensville Shale: yellowish gray and green-gray, weathers light to medium gray, shale; very calcareous, shaly bedded, moderate to well indurated, common limonitic and hematitic staining, occasional shell hash lenses; very fossiliferous with *Derbyia*, *Composita*, fenestrate and ramose bryozoa, *Neochonetes*, crinoids, echinoid plates and spines, productid shell fragments and spines, *Reticulatia*, sparse *Ditomopyge*, *Enteletes*, *Meekella*, *Straparolus*, ostracodes, *Petrocrania?*, and rare shark teeth, fossils are commonly articulated and large (robust) in form.	0	7	0.18
THREEMILE	W1.3	20.	Threemile Limestone: medium gray, weather yellow-gray, skeletal, calcarenite; thin bedded at base medium bedded toward top, cherty, well indurated, slabby, argillaceous in upper portion of the unit, occasional thin lenses of finer grained material; fossils: abundant fenestrate and ramose bryozoa, common brachiopod shell fragments, sparse crinoids, echinoids, productied spines, and ostracodes, elongate fossil fragments alined subparallel to bedding, occasional bryozoa fragments partially replaced by chert, most fossils are fragmented and show signs of abrasion (subrounded); calcarenite: brachiopod, bryozoan, biomicrite, (wackestone).	0	11	0.28
THREEMILE	W1.3	19.	Threemile Limestone: very light gray to light pale yellow-orange, weathers light yellow-gray, skeletal, calcarenite; thick bedded, well indurated, cherty, common yellow-orange (fe-oxide) staining; fossils: abundant fenestrate bryozoa, common brachiopod shell fragments, sparse crinoids, echinoid plates and spines, productid spines, and ostracodes, some fossil fragments (particulary bryozoa) partially replaced by microcrystalline and/or chalcedonic quartz, many fragments show signs of abrasion (subround to occasionally rounded), with a slightly recrystallized micritic matrix; calcarenite: chert bearing, brachiopod bryozoan, biomicrite, (wackestone).	0	9.5	0.24

Section W1 continued

THREEMILE	W1.3	18. Threemile Limestone: very light gray to light pale yellow-orange, weathers pale yellow-orange, skeletal, calcarenite; thick bedded to massive, chalky, moderate to well indurated, cherty, porous with common solution pits and vugs, sparse to common rosette and rectangular crystal molds throughout, with a 4 in. zone of abundant vugs,rosette and rectangular crystal molds located 40 in. from base of unit, unit becomes slightly coarser grained toward top; chert; 5 zones of chert are present; 9 in. thick layer bedded chert at base; light gray to dark blue-gray, occasional opal fracture-fillings, fossiliferous same as limestone; 3 in. layer bedded chert, 21 in. from base; dark gray center grading outward to light gray and white, fossiliferous same as limestone; two layers of nodular chert (each 1 to 2 in. thick), 27 in. and 35 in. from base, same description as above; 8 in. layer of bedded chert at top of unit, dark gray and dark blue-gray to light gray, mottled in appearance, common irregular patches of calcareous material, upper 3 to 4 inches somewhat nodular in appearance, occasional chert nodules (up to 3 in.) in a 4 in. zone below bedded chert, fossiliferous same as limestone; fossils: common to locally abundant fenestrate bryozoa, sparse Composita (found mainly in lower portion of unit), Enteletes, braciopod shell fragments, crinoids, echinoids, productid spines, and ostracodes; fine calcarenite: cherty, brachiopod, bryozoa biomicrite, (wackestone).	5	5	1.65
		17. Threemile Limestone: pale yellow-orange to light gray, weathers yellowish gray, skeletal, calcarenite; nonbedded, cherty, well indurated, argillaceous, common rosette crystal molds some filled with opalline silica; fossils: Composita, fenestrate and ramose bryozoa, sparse Derbyia, crinoids, echinoids, productid shell fragments, Reticulatia, producid spines, ostracodes, and rare trilobites, some fossils partially replaced by chert; calcarenite: chert bearing, argillaceous, bryozoan, brachiopod biomicrite, (wackstone).	0	5	0.13
		16. Threemile Limestone: variegated (yellow-orange, yellow-gray, green-gray, and dark gray; mottled), weathers pale yellow-orange, shale; shaly bedded, flaggy, moderate to well indurated, very calcareous, occasional rosette and rectangular molds; very fossiliferous with common Derbyia, Composita, crinoids, Neochonetes, Reticulatia, fenestrate and ramose bryozoa, echinoid plates and spines, sparse Enteletes, productied spines, ostracodes, and rare shark teeth, most speciments are articulated and large (robust) in form.	0	7	0.18
	W1.2	15. Threemile Limestone: light gray to yellowish gray, weathers pale yellow-orange, skeletal, calcarenite; massive, well indurated, common to abundant rectangular and rosette crystal molds in lower 5 in., less fossiliferous in the lower and upper portions of the unit, finer grained at base; chert; 5 layers of nodular chert; dark gray to dark blue gray in the center, grading outward to light gray and white, thickness of light colored border varies from being absent to comprising the whole nodule, fossiliferous same as limestone; nodular chert zones are 2 to 3 in. thick and are found 2 in., 7 in., 11 in., 15 in., and 21 in., from the base of the unit; fossils: brachiopod shell fragments, bryozoa, Composita, crinoids, echinoids, productid shell fragments and spines, and rare trilobite fragments, with a conspicuous 2 to 4 in. zone of abundant Wellerella, 17 in. from the base of the unit; matrix is a slightly recrystallized micrite; fine calcarentie: cherty, bryozoan, brachiopod, biomicrite, (wackestone).	2	2	0.66

Section W1 continued

THREEMILE	W1.2	14. Speiser Shale: light gray and light yellow-gray with dark gray mottles, weathers light green-gray, shale; calcareous, shaly bedded, platy, moderate induration, occasional calcite geodes; sparsely fossiliferous with brachiopod shell fragments, bryozoa fragments, small crinoid columnals, echinoids, Aviculopecten, productid shell fragments (Reticulatia), and rare Enteletes.	0	3	0.08
		13. Speiser Shale: light gray and light yellowish gray to dark gray (mottled), weathers light green-gray, shale; very calcareous, shaly bedded, moderate to well indurated, occasional argillaceous shell hash lenses; very fossiliferous with crinoids, Derbia, Composita, Neochonetes, fenestrate and ramose bryozoa, echinoid plates and spines, productid brachiopods (Reticulatia, Linoproductus?), productid spines, ostracodes, sparse Aviculopecten, Orbiculoidea shell fragments, and rare Enteletes, and shark teeth, most specimens large (robust) in form and commonly articulated, unit becomes less fossiliferous toward the top.	1	2	0.36
	W1.1	12. Speiser Shale: variegated (light gray, green-gray, yellow-orange, and dark gray), weathers light green-gray, shale; calcareous, silty, shaly bedded, moderate induration, sparse irregular masses of crystalline calcite (secondary in origin); sparsely fossiliferous with sparse to locally common Orbiculoidea, Aviculopecten, productid shell fragments, sparse to rare bryozoa fragments, Straparolus, and ostracodes.	0	7	0.18
		11. Speiser Shale: same as unit 12, more fossiliferous with Aviculopecten, productid shell fragments and spines, ostracodes, and sparse to rare bryozoa fragments.			
		10. Speiser Shale: light pale yellow-orange to medium gray (mottled), weathers pale yellow-orange, skeletal, medium calcarenite; thick bedded to massive, well indurated, sparse to locally common large (2 in. scross) vertical burrows, sparse micritic limestone intraclasts (0.1 in. average diameter) in middle and upper portions of the unit, lower portion of unit is finer grained than middle and upper portions, occasional lenses of fine argillaceous material, medium gray, in upper portion of the unit; fossils: common bivalve shell fragments, Aviculopecten, Aviculopinna? ostracodes, productid spines, and rare productid shell fragments and forams; medium calcarenite: argillaceous, intraclast, molluscan biomicrite (wackestone).	2	1	0.64
		9. Speiser Shale: green-gray to yellowish gray, weathers light greenish gray, shale; thinly laminated, platy, calcareous, moderate indurations, with occasional plant fossils; fossiliferous with ostracodes and rare shell fragments.	0	1.5	0.04
		8. Speiser Shale: green gray, weathers light green-gray, claystone: nonbedded, silty, blocky, well indurated, common yellow-orange Fe-oxide staining: fossiliferous with abundant ostracodes and rare shell fragments.	0	2	0.05
		7. Speiser Shale: white, yellow-gray, and green gray (mottled), weathers light yellow-gray, skeletal, calcilutite; single bed, moderate to well indurated; fossils: common ostracodes in fine micritic matrix; calcilutite: ostracode biomicrite (wackestone).	0	2	0.05
		6. Speiser Shale: green-gray, claystone; silty, nonbedded, blocky, well indurated, common yellow-orange Fe-oxide staining: fossiliferous with abundant ostracodes.	0	7	0.18

Section W1 continued

		Description			
FUNSTON		5. Speiser Shale: green-gray and meduim gray (mottled), weathers light green-gray, claystone; nonbedded, blocky to flaggy, silty to sandy, with sparse root mottles; fossiliferous with sparse ostracodes.	1	2.5	0.37
		4. Speiser Shale: green-gray to meduim gray (mottled), weathers light green-gray, shale; shaly bedded, platy, calcareous, silty, sparse plant fragments; fossiliferous with ostracodes.	0	2	0.05
		3. Speiser Shale: green-gray to dark gray (mottled), weathers light green-gray, shale; shaly bedded, fissile to platy, calcareous, silty, common to locally abundant plant fragments; Disaggregated samples shows sparse ostracodes and shell fragments.	1	5	0.43
		2. Speiser Shale: meduim gray, yellowish gray, and dark gray (mottled), calcirudite; single bed, argillaceous and silty, well indurated, common plant fragments, abundant small (0.25 in. on average) micritic limestone intraclasts in a fine to locally coarse granular matrix, elongate intraclasts aligned subparellel to bedding, conglomeritic, becomes coarser grained toward top; fossiliferous with sparse ostracodes, shell fragments, and algae, seen as coatings on some intraclasts and shell fragments (nearly all shell fragments are algal coated).	0	15	0.04
		1. Speiser Shale: green-gray, weathers light green-gray, claystone; nonbedded, blocky, calcareous, silty, moderate to well indurated, occasional to common root mottles and traces; fossiliferous; disaggregated sample shows rare ostracode(?) shell fragments.			

Thin-section data was used to suppliment descriptions of the following units: 2, 15, 19, 20, 23, 28, and 30.

Disaggregated shale data was used to suppliment descriptions of the following units: 1, and 3.

HIERARCHAL GENETIC STRATIGRAPHY OF THE WREFORD LIMESTONE FORMATION (LOWER PERMIAN, GEARYAN) IN NORTHEASTERN KANSAS

by

TERRY R. BARRETT

B.S., University of Colorado, 1984

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

(Geology)

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

ABSTRACT

Detailed analysis of the Wreford Limestone Formation (Lower Permian, Gearyan) in northeaatern Kansas was carried out utilizing a hierarchal genetic stratigraphic approach (i.e., after Busch and West, 1987) as opposed to the traditional cyclothem approach. Lithostratigraphic and paleoecologic data were used to define and correlate fifth- and sixth-order transgressive-regressive units (T-R units) of the study interval in Marshall, Riley, Pottawatomie, Geary, and Wabaunsee counties, Kansas.

The standard Wreford section, extending from the upper part of the Speiser Shale to the middle part of the Schroyer Limestone (upper Council grove Group), contains nine sixth-order genetic surfaces (W1.1 thru W2.2) bounding all or parts of ten sixth-order T-R units. These sixth-order units compose one complete fifth-order T-R unit (the Threemile fifth-order T-R unit), the upper part of a subjacent fifth-order T-R unit (the Funston fifth-order T-R unit), and the lower part of a superjacent fifth-order T-R unit (the Schroyer fifth-order T-R unit). These sixth-order T-R units shallow upward and, therefore, Punctuated Aggradational Cycles (Goodwin and Anderson, 1985).

The Threemile fifth-order T-R unit has an average thickness of 10 m and consists of seven sixth-order T-R units (W1.1 thru W1.7). The thickness of the sixth-order T-R units ranges from 0.3 m to 2.5 m. The Threemile fifth-order T-R

unit probably represents a time interval of about 300,000-500,000 years (Busch and West, 1987). The sixth-order T-R units represent time intervals of about 43,000-71,000 years.

Using of sixth-order T-R units detailed paleogeographic maps were constructed for times of maximum transgression and maximum regression with in each sixth-order T-R unit. Isopach maps and paleostructure-contour maps were also constructed for sixth-order T-R units.

The mapa indicate that structural features influenced topographic highs and lows, which in turn effected both the thickness and depositional environments of the sediments with in the Wreford Limestone. For example, thinning of sixth-order T-R units and shallowing of facies took place over structural highs in the northeast, northwest, and southern portions of the study area. Thickening of sixth-order T-R units and deepening of facies in general corresponded to structural lows.

Field and labratory data indicate a diagenetic origin for the conspicuous nodular and bedded chert found within the Wreford Limestone. It is suggested that much of the chert formed as a result of replacement of Permian age evaporites.